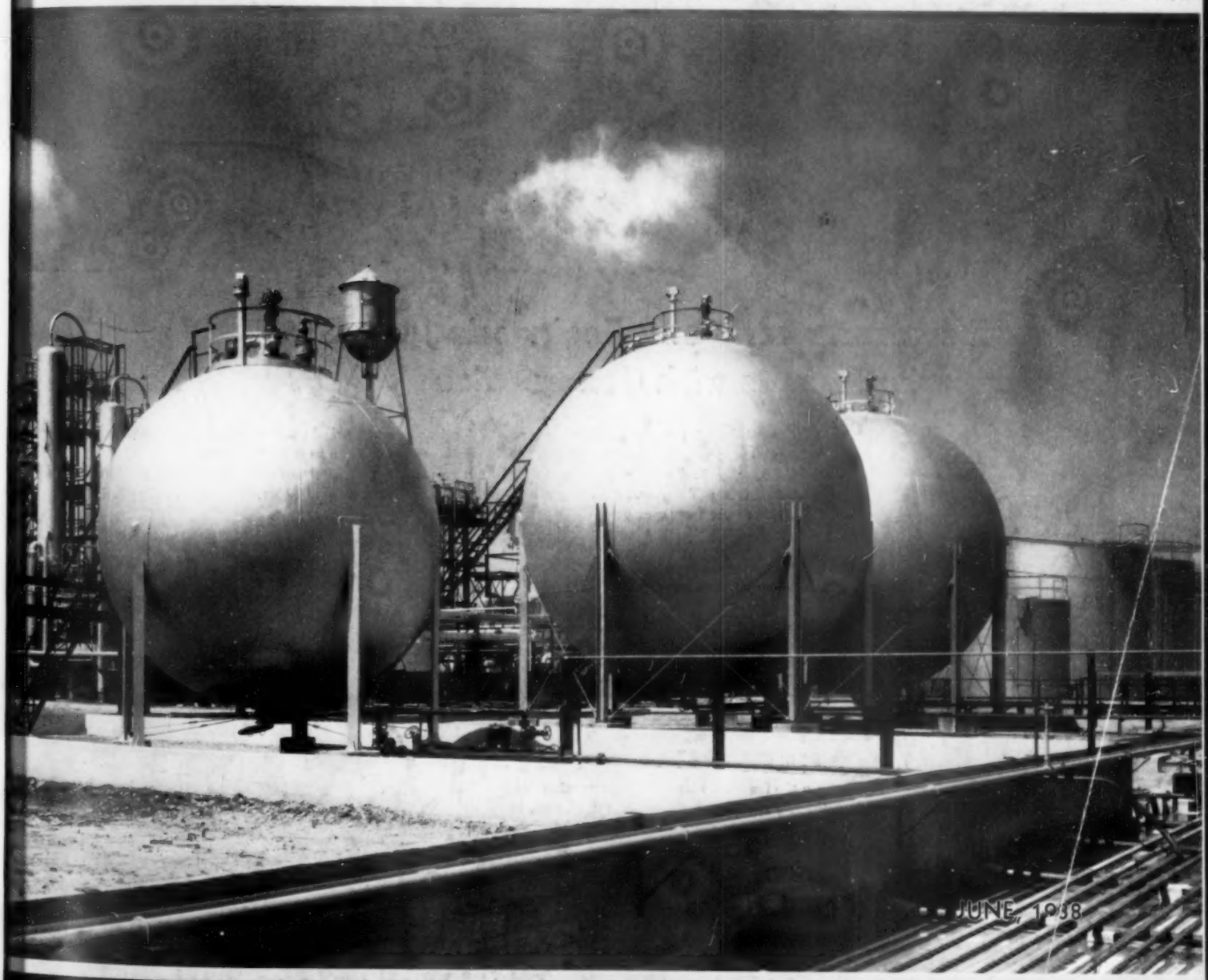
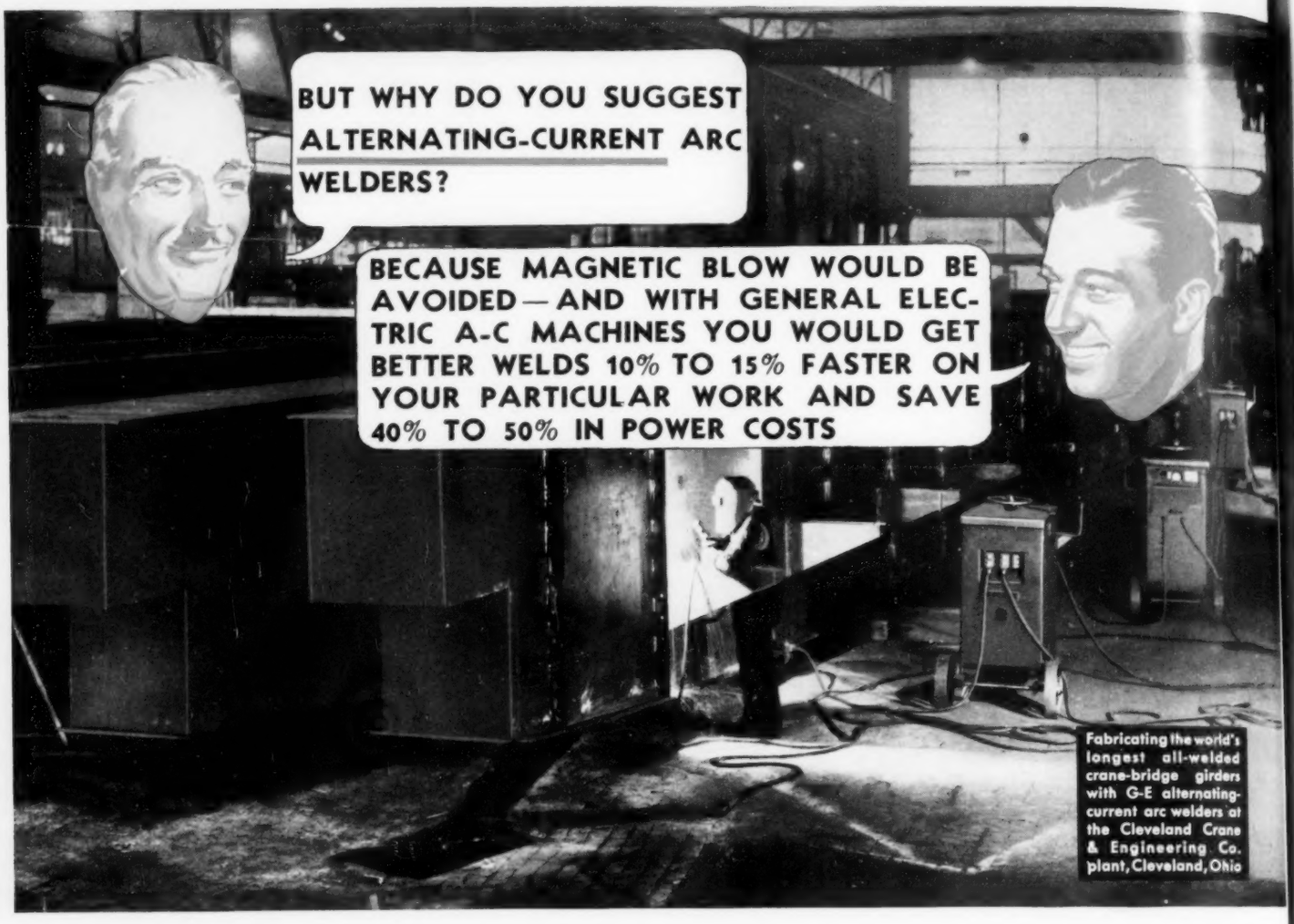
The Welding Journal



JUNE, 1938

The Journal of the American Welding Society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Published for the Advancement of the Science and Art of Welding

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Hortonspheres at the Gulf Oil Corporation at Port Arthur, Texas. There are 2—4000-bbl. and 1—1,000-bbl. Hortonspheres, 35 ft. 3 in. diam. and 22 ft. 3 in. diam., respectively.

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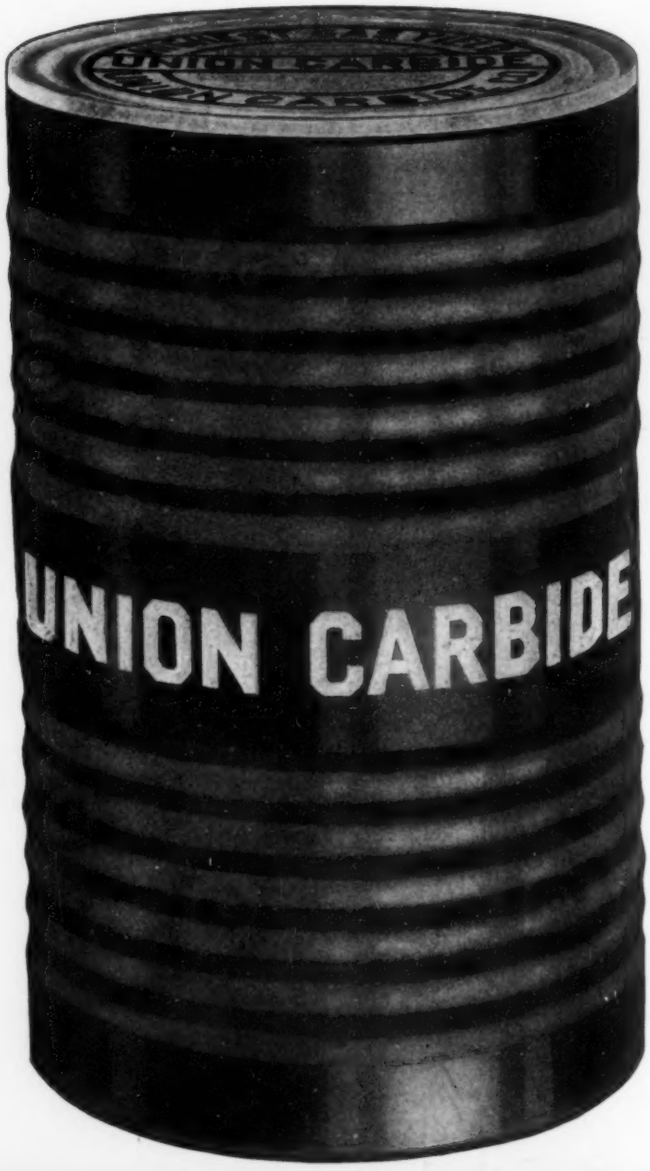

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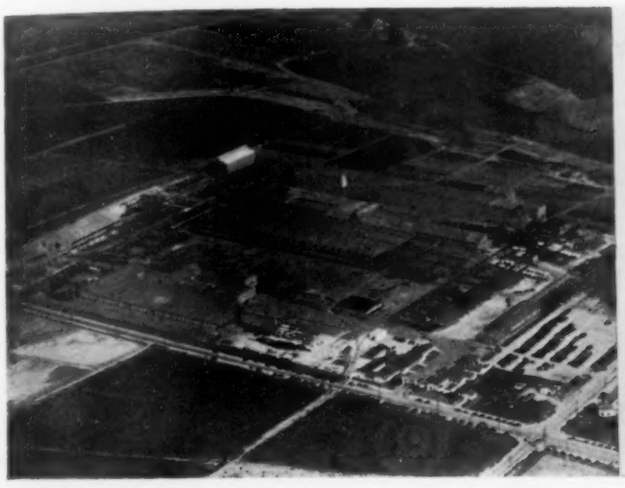
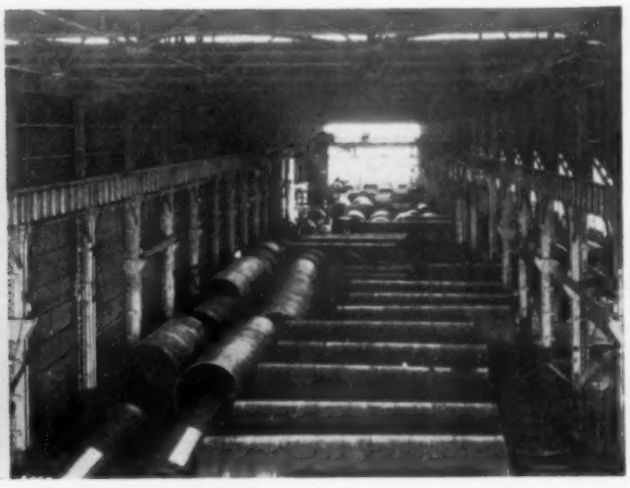




Figs. 1 and 2—Exterior and Interior Views of Plant

SHOP FABRICATION OF LARGE Diameter Welded Steel Pipe*

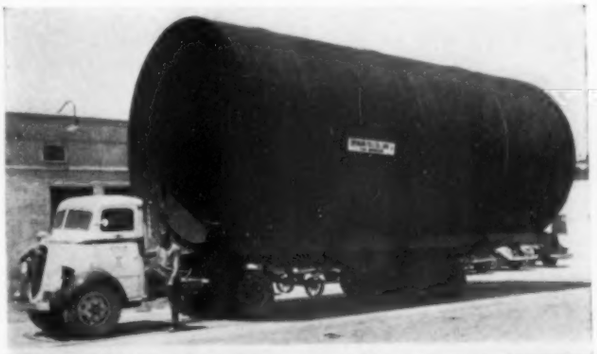
By LEROY A. MUFFLER†

WHEN man comprehended the significance of the circle, the route to modern civilization was charted. When the principles of the circle were adapted to wheels, progress began to roll forward. As further exploration brought about the replacement of the hour glass with timepieces motivated by wheels, the Dark Ages were ended, the circle no longer thought of only in mathematical terms. Its utilitarian purposes were recognized. Its mysticism from then on was to be shared with its practical purposes.

Still, long before this advancement, the ancients had given usage to the form that was to become so identified with the transportation of water that the early dictionaries defined pipe as "a channel for the passage of water." Thus, the subject of pipe, as pipe, is not unorthodox. Nor is large diameter pipe new or unusual. Not even is the idea of large diameter welded steel pipe unconventional. Only when we consider welded steel pipe in the light of modern welding processes do we appreciate how far it has left the beaten path, by the nonadherence to the dogma that weight must necessarily mean strength, that size is synonymous with efficiency.

Speaking before a recent meeting of the American Institute of Steel Construction, Mr. Thomas Beck, president of the publishing firm of Colliers, very graphically described his first trip on one of the trans-Pacific clipper

Fig. 3—A Welded One Piece Unit



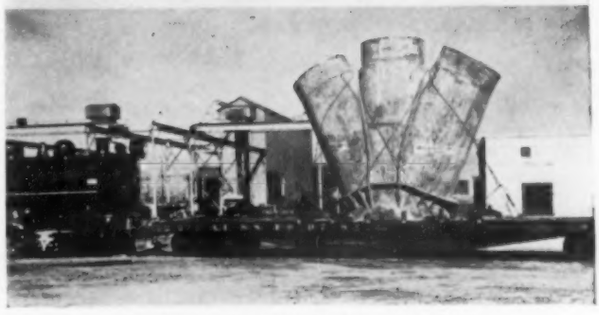


Fig. 4—A 11-Foot 6-Inch Connecting Link

* Paper presented at Western Metal Congress and Western Metal Exposition, Los Angeles, California, March 21–25, 1938.

† Engineer, Consolidated Steel Corporation, Ltd., Los Angeles, California.

Fig. 5—Large Pipe Crossing Santa Ana River

ships. Observing, as he put it, "two large fluked duralumin anchors fastened to very small cables no bigger than my little finger," he expressed his doubts to the pilot whether they could hold the ship at anchor. Being assured they would not only hold the clipper fast, but might well equally as certain hold a trans-Atlantic liner, he posed the query, "Why then, do we have links of enormous size and tremendous weight on those liners?" The air skipper's prompt reply was "Because they have not dissociated the idea of weight and size from that of strength. They seem to think they are the same, and they are not."

As fabricators of welded steel pipe we have gone along with the spirit of the pilot's retort. We have approached the job in the characteristic attitude of the welding fraternity that size and efficiency are not inseparable Siamese twins. Our subscription has been to the kind, manner of application, preparation of surfaces, and definite capacity of joints, rather than to a dependence on bulk.

In this discussion the particular pipe to be elucidated upon is that part of the water transmission line carrying the waters of the Colorado River to the Pacific Coast cities, as manufactured by the Consolidated Steel Corporation, Ltd. of Los Angeles (plant view, Figs. 1 and 2) for the Metropolitan Water District of Southern California. However, before getting along with the subject matter, it seems not amiss to at least acknowledge the contributions of so many individuals, corporations, and groups to the general science of welding. They have made the fabricating of pipe, as we speak of it here, possible. Without the foresight of the steel mills the larger size plates used now would not be available to permit the large jointless one piece units, as is shown in Fig. 3. If the manufacturers had been less cooperative and searching, the larger electrodes would be absent and with them the high speed single pass welding process. It will be remembered that until but a few years ago single-pass welding was not commercially possible with steel in excess of $1^1/_4$ inch thick.

The metallurgist has been as diligent too, so today we are working with materials of a far greater uniformity of composition and texture than we would have otherwise. Then there have been the researchers, the welding machine builders, the trade journals and of course such societies under whose auspices we meet this week. All, and more have projected welding into its present state of development. The utility companies and the various suppliers, likewise, have been very much in the picture not to forget the technicians with their advances in radiography and X-rays. And, even though it may be heresy to current popular opinion, finance must receive its due in providing the wherewithal to underwrite the entire development.

We would be lacking too, if we did not reflect on the contribution the Water District engineers have made to the entire industry by their diligent research work that preceded the writing of their specifications. Undoubtedly, volumes of material have been accumulated as the result of their extensive investigations and experiments. But details must be left to someone more intimate with their efforts. We must be content here to merely remark in passing an appreciation of their activities.

It is a far cry from the surplus cannon barrels used after the Napoleonic Wars for water pipes to the 11 feet 6 inches diameter pipe and connecting links, as Fig. 4 portrays, stretching across mountains and deserts, not far from where we meet today. And, while welded pipe up to a quarter of a century ago was limited to 2 feet 6 inches diameter, today, installations are practically without limit as to size, and welding is no longer restricted to metals not in excess of an arbitrary established tensile strength. When we consider a recent specification calling for thirty foot diameter pipe of $2^3/_4$ inch thickness we can in some measure appraise the breadth of development in the use of welding. Tennyson's "I watched the little circles die" seems apropos to any review of modern welded pipe.

The pipe fabricated for the Cajalco-Fontana section,

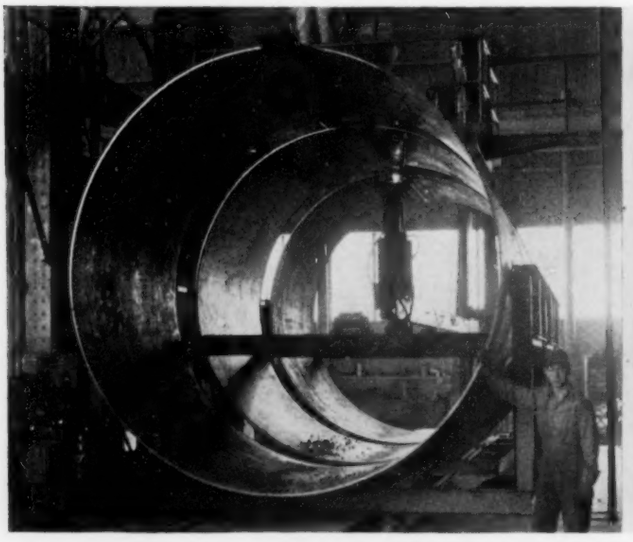


Fig. 6—Welding Head

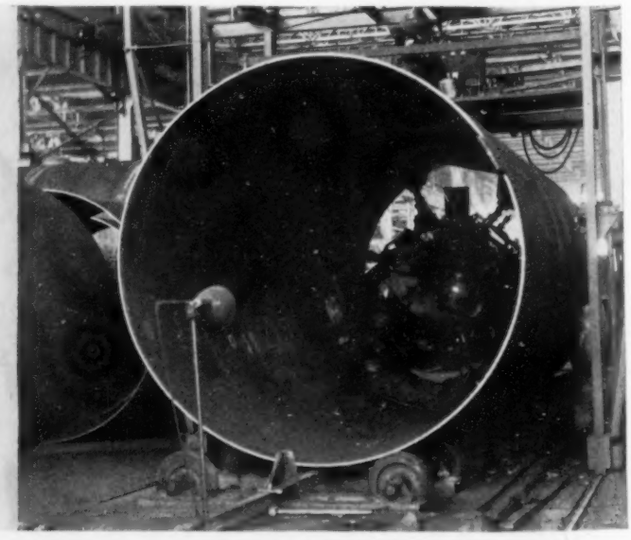


Fig. 7—Spider Rig Helps Maintain Roundness

which included the crossing of the Santa Ana River, (see Fig. 5) ranged from 9 feet 8 inches diameter to 11 feet 6 inches diameter. The shipping sections were generally 33 feet 4 inches long and made up of four 100 inch wide plates with the longitudinal seams staggered. The steel used was A. S. T. M. A-10-34 and A-78-33 of thickness varying from $^{9}/_{16}$ inch to $^{31}/_{32}$ inch with the specifications calling for "a true circle of specified diameter throughout the entire length so as to produce a finished pipe truly round, and free from dents, kinks and abrupt changes in curvature." It was further specified that "The outside circumference of the finished pipe shall not be less than its theoretical value by more than $^{3}/_{8}$ of an inch."

As in the making of any pipe the sheets were bevel-planed and rolled to the diameter required, these operations, however, involved nothing out of the ordinary. This beveling of the edges provided the welding groove which varied with the thickness of the plate and ranged from 30 degrees to 60 degrees in accordance with the schedule of standards in use, leaving in every case a "face" or "nose" of $^{1}/_{8}$ inch of the basic metal on the interior. This face provided a smooth unbroken surface on the inside for the spider jig used to line up the joint and the base for the interior weld.

Previous to the beveling, however, the effective surfaces that were to be adjacent to the weld were shot-blasted clean of all scale and foreign matter that would have contributed to oxidation and the resulting porosity in the weld. While the specifications permitted a choice of several methods of preparation of the surfaces for the welds, investigation and experiments led to the choice of shotblasting as not only satisfactory but economical as well.

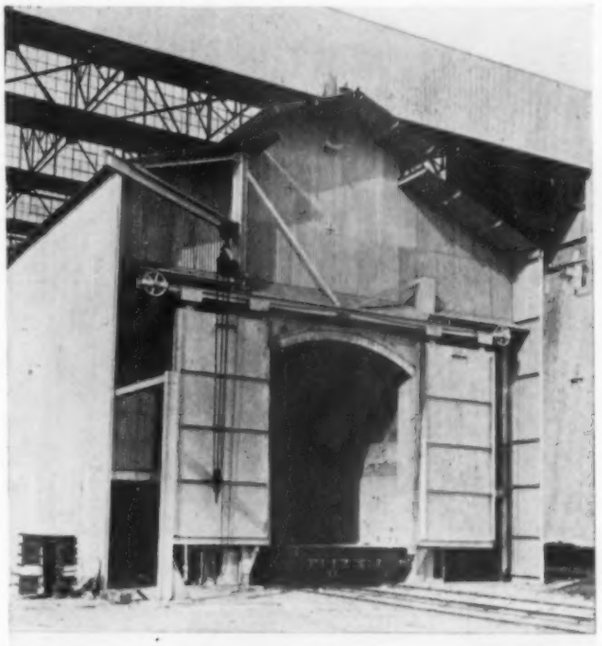
The plates were then rolled and after being tack-welded into shape the "cans" were welded longitudinally traveling on a moving rig through a fixed welding head. The welding head was equipped (Fig. 6) with a stationary water-cooled back-up designed to absorb the surplus heat and control the weld-metal penetration. To each section was tack-welded a small starting plate on one end which permitted an uninterrupted and uniform weld the entire length of the section. For each 400 lineal feet of combined longitudinal and circumferential weld a test plate was attached to the pipe sections. One of the requirements of the tests being that the tension tests show a joint efficiency of not less than 100% of the parent metal. Bend and nick tests were called for in conformance with the A. P. I.-A. S. M. E. Code for Unfired Vessels.

It has been aptly said that the fundamental purpose of any symposium is to stimulate thought on a particular subject. The result of the tests suggests a continued further liberation in the use of welding with the implication that a reduction in the variation in yield-point strength of the parent metal would stretch the horizon of both the use of steel and welding.

For the pipe we are discussing a standard grade steel was used and the meeting of the requirement in the welds was hardly a problem. Tensile strength developed in the weld-metal in many cases was over 60,000 pounds per square inch and elongations up to 50% were not uncommon. Usually these properties were higher in the weld-metal than in the parent metal. Adequate welding materials properly used by qualified mechanics invariably surpass the demands made upon them.

But to return to the particular project under discussion. Following the longitudinal welding we were at the interesting part of the job and at the problem that was to be solved if the entire effort was to be viewed as successful. Not only did the specifications confine any

Fig. 8—Stress Relieving Furnace



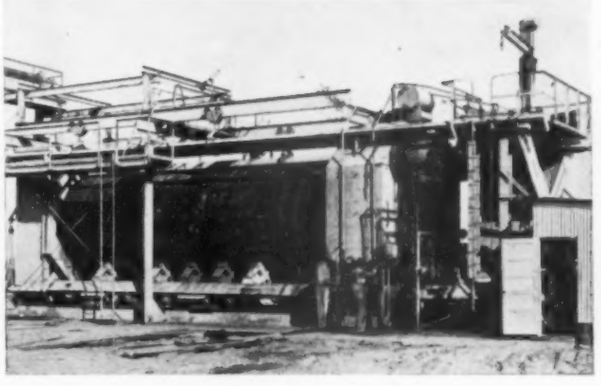
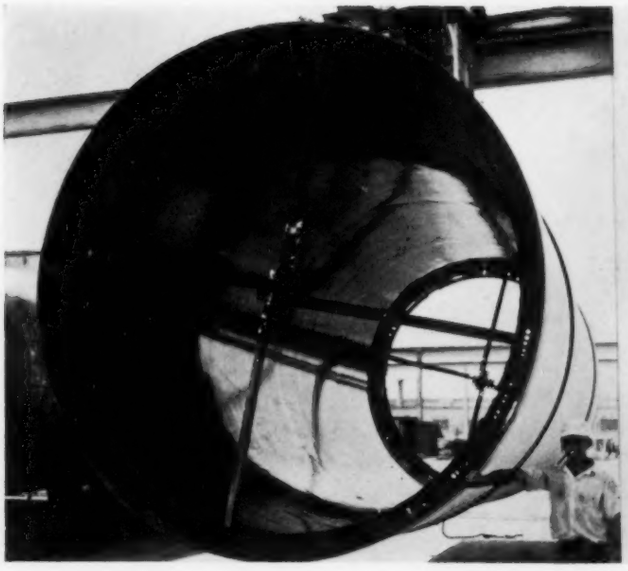


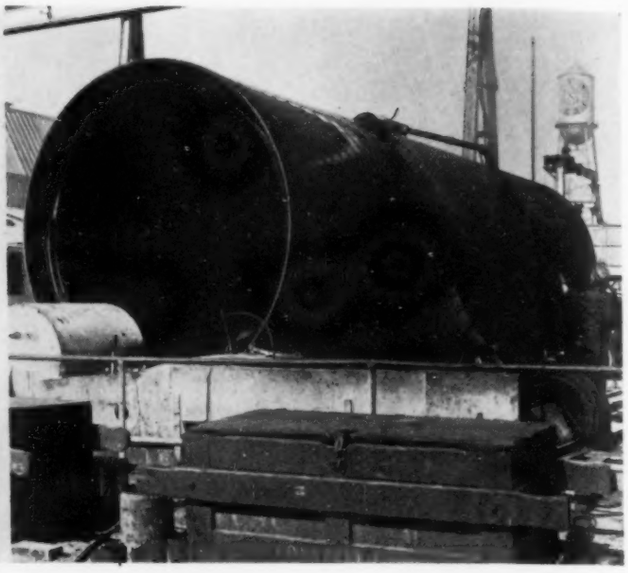
Fig. 9—Pipe Tested Hydraulically

out-of-roundness to an extremely narrow range, but the size of the pipe, the thickness of metal, and the type of protective coating, both inside and outside, together with the method of their applications, all conspired to require the "cans" be made accurately round and rigidly maintained that way through all the operations yet to follow.

After considerable study a spider rig, as shown in Fig. 7, was developed. This equipment in addition to rectifying any cylindrical discrepancies in the "can" before welding, served as a heat control that prevented warping or bagging during the welding operation. With a rim, adjustable for the several diameters of pipe involved, of steel for the wearing surface, actuated by hydraulic pressure, the exact diameter was established and maintained throughout the welding of the circumferential joints. To reduce the tendency to distort the rim of the spider was equipped with copper shoes extending around the entire perimeter unbroken only by the pressure arms of the steel rim.

With the bevel grooves providing a uniform track for the guide wheels as the pipe revolved, the electrode was deposited in a bath of molten silicate flux flowing before the arc, protecting it from oxygen contamination and excluding "atmosphere during the process of deposition" as called for by the specifications.





Figs. 10 and 11—Finished Interior and Exterior of Pipe

The electrode used was an alloy steel with a copper wash coating that proved entirely satisfactory and justified the importance with which electrodes have come to be considered.

The current was taken direct from the 2200 volt incoming power lines and reduced by a transformer to approximately 110 volts A.C. The control was a push-button device that permitted a control of the amperage ranging from the lowest to the highest in an almost infinite number of steps. This arrangement was not only efficient from a power consumption standpoint but proved highly desirable in that the regulation was excellent and undisturbed by power fluctuations resulting from other operations in the plant. The arc control was accomplished by unique thyratron tube control whereby the A.C. arc voltage was rectified and was used to control the speed of the D.C. electrode feed motor.

The welder was equipped with a speed indicator ammeter, automatic electrode feeders and a voltage meter. With tube control of the arc the basic factors were constant and under automatic control at all times with the personal equation of the weld being reduced to a minimum. The process, modified to suit the particular condition, was the Unionmelt method that has been appropriately referred to as "resistance fusion" rather than what is called more generally "electric-arc" welding in which the weld, while protected, permits speed of operation with less distortion and develops a truly automatic process.

Upon completion of the assembly of each shipping section the one end was belled and then the piece tested and made ready for the stress-relieving furnace where it was subjected to heating between 1100 and 1200° F., timed at 1 hour per inch thickness with a minimum of 40 minutes for all units where the thickness exceeded $^5/_8$ of an inch. The discharge end of the furnace is shown in Fig. 8. Here the semi-finished product was ready for testing under hydrostatic pressure in the testing machine shown in Fig. 9 on the basis of $P = \frac{44{,}000 \times t}{D}$, with "$t$" representing the minimum thickness in the section tested and "D" the internal diameter in inches.

We have referred to the sections here as semi-finished. Semi-finished because with the hydraulic engineer buying flow efficiency now rather than size of pipe and controlled life of pipe instead of reliance alone on thickness of metal to withstand corrosion, pipe, as it comes from the welding shop is but semi-finished. This leads us to a discussion of coating—inside and out. To the inside was applied a coating of coal tar primer, followed by a coating of coal tar enamel. The exterior surfaces were coated with similar materials to a thickness of $^3/_{32}$ of an inch. Except for the exposed sections crossing the Santa Ana River, the exteriors were further covered with Gunite reinforced with wire mesh to a thickness of $1^1/_2$ inches for some sections and $^3/_4$ inch thick without reinforcement for others. This, however, is a subject in itself as our program indicates. We can therefore leave it in the hands of the able speaker to whom it is assigned, except to submit here illustrations of a finished interior and the final touching up of an exterior (Figs. 10 and 11).

Still, since the nature and methods of application of linings and coatings are to a large degree dependent upon welding of the pipe in the first place and offer problems to the welder not otherwise present, it should be noted that to successfully apply spun coatings, either bitumastic or, of a cement base, not only is a smooth and even surface required but the roundness of the pipe is extremely essential. Especially true is this when the application is by centrifugal action wherein the tremendous forces developed by speeds in excess of 2000 perimeter feet per minute subject the pipe to a most drastic test of both roundness and delicate balance. One needs but little imagination to visualize what would happen to a pipe encumbered with heavy reinforcing plates and riveted connections.

Three men were digging a ditch. The first when asked, "What are you doing down there," replied, "Working for $6.00 a day." Proceeding to the second man the same question was met with the answer, "I'm digging a ditch for a foundation." When again the question was put, this time to the remaining digger, his response, with interest and enthusiasm, was, "I am helping to build a magnificent cathedral."

We like to feel we share the attitude of this third laborer. We take pardonable pride in that we have not been merely working at making pipe but that we have helped build a great water distribution system—a lifeline.

DESIGN AND FABRICATION of High Temperature and High Pressure Piping*

By F. C. FANTZ†

THE increased use of high pressure and temperatures in the steam plants and oil refineries has forced the designer to look for a better means of joining the tubular sections that make up the piping system. The high cost of flanged joints and the difficulty of maintaining tightness under the severe conditions have led to the use of welding wherever possible.

The challenge has been met and future developments along this line will find welding keeping up with the procession as the accepted method of fabrication.

Flanged joints, if used at all, are limited to such places as require dissembling for cleaning or other purposes.

Practically all present-day high temperature piping in control stations is carbon molybdenum steel, allowing a reduction in weight of about 40%.

Oil refineries and industrial piping designs call for high strength and corrosion resisting alloys. This means a change in welding technique and has made stress relieving or heat treating of the finished assembly necessary.

Special shapes, bends etc. are fabricated in the piping contractor's shop insuring maximum weld quality and freedom from locked-up stresses.

WELDING FITTINGS

Manufacturers have kept pace with welding designs by providing a line of fittings designed especially for welding and made of materials and wall thicknesses to meet most of the A.S.A. schedule numbers now in general use.

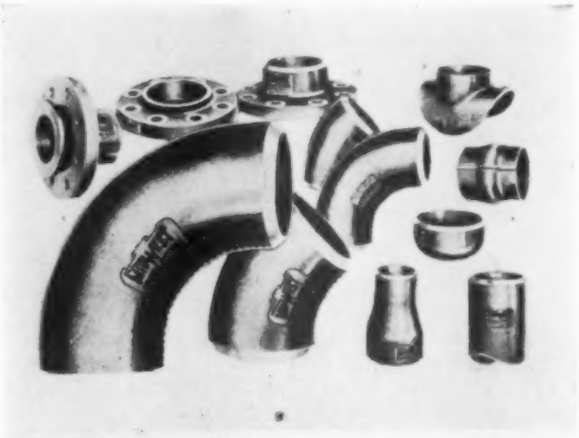
Flanges for high pressures should be either the butt-welding type which are welded direct to the end of the pipe; or the Van Stone type, in which case the end of the pipe is upset to form the gasket bearing surface. In either case, any of the various types of facings can be applied. The Van Stone type has the advantage of a loose flange making it a simple matter to line up the bolt holes during erection.

Elbows are regularly made in 90 to 45 degree angles with and without tangents. The ends are prepared for welding. Inasmuch as the cross section of an elbow is the same throughout, other degrees can readily be made by cutting either in the shop or in the field.

Reducers are available in both the Concentric and Eccentric types. The minimum diameter of the small end being one pipe size below half of the larger diameter, i.e., a 6 inch x $2^1/_2$ inch, or 8 inch x 3 inch (Fig. 2).

Welding Heads are used to close headers and ends of a line and to take the place of blind flanges in other designs.

Fig. 1—Welding Fittings



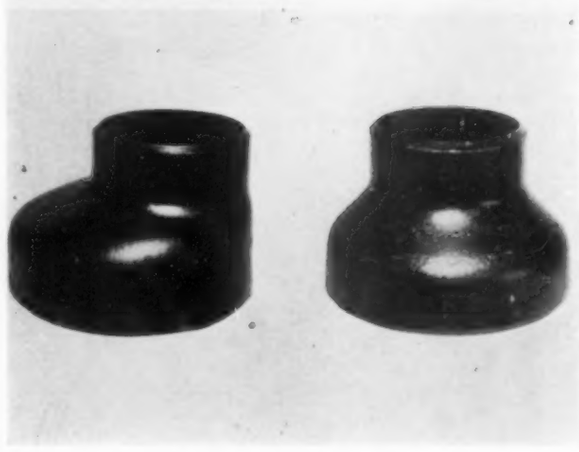


Fig. 2—Reducers

Tees are available in most sizes and in some reducing combinations.

Sockets. In the small sizes of pipe (from $^1/_8$ inch to $1^1/_2$ inches), a fitting known as the Socket type is sometimes used in which the end of the tube is inserted into a recess and held by a fillet weld.

Valves and other auxiliaries are now being made and installed with welding ends instead of the usual flanges. Some valves are being installed without the large bonnet flanges, the bonnet and body of the valve being joined by welding.

The materials used in the inside of valves, such as seat rings, disks and stems, have been improved to such an extent that it is seldom necessary to open up a valve for

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† Vice-President, Midwest Piping & Supply Company, Inc.

repairs. Renewal or repair of a valve seat should not be undertaken except at the factory.

With this much progress made, the author sees no reason why the high pressure valve of the future should not be fabricated from wrought steel or alloy shapes and entirely welded together. The valves could be made from 30 to 50% less in weight and with greater assurance of trouble-free operating life.

WELDING

The welding used in a piping system can be divided into three general classes; namely, (*a*) Butt Welds, (*b*) Fillet Welds and (*c*) Branch or Intersection Welds. The latter is a combination of the Butt and Fillet Welds.

(a) Butt Welds

This is the easiest form of weld to make and at the same time produces a joint with the same factor of safety as the parts joined. The ends to be welded should preferably be machined in order to produce a smooth and uniform welding groove. When cut with a gas cutting torch, the surfaces should be ground or otherwise smoothed to prevent slag inclusions and lack of fusion in the finished weld.

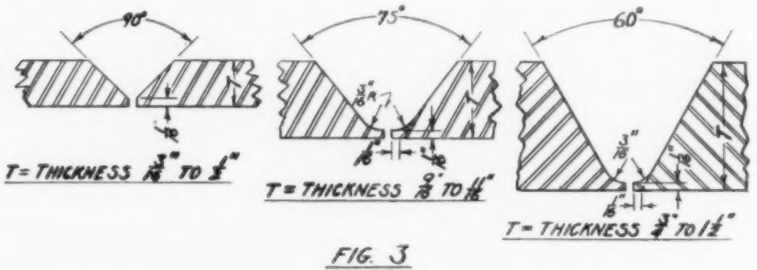


FIG. 3

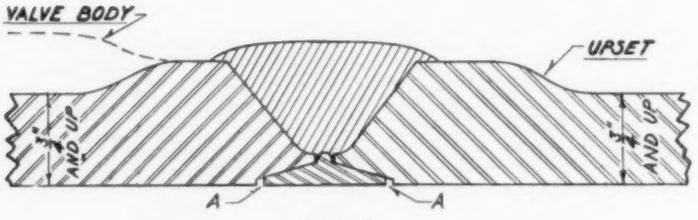


FIG. 4

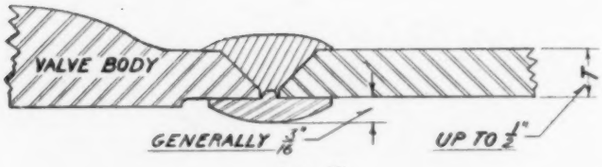


FIG. 5

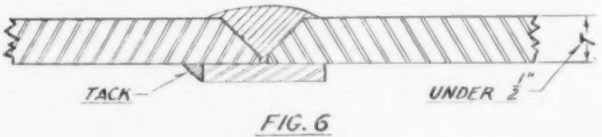


FIG. 6

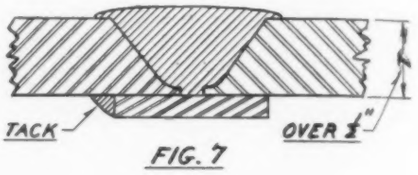


FIG. 7

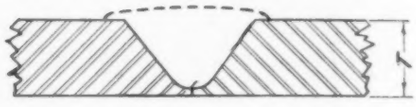


FIG. 8

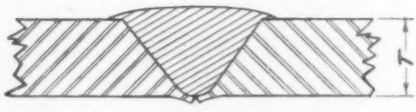


FIG. 9

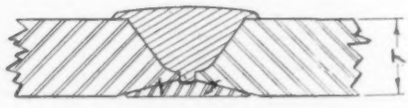


FIG. 10

Fig. 4
T = pipe wall thickness
Upset generally T plus 25—
Note spacing at "A" to allow shrinkage of weld
Easily assembled due to tapered ring
Full inside diameter maintained
Expensive to upset and machine

Fig. 5
Pipe ends not upset
Full strength maintained
Difficult to assemble due to straight ring and non-uniform inside diameter of pipe
Flow restricted by reduced inside diameter

Fig. 6
Tack to hold ring during assembly
Full strength maintained
Difficult to assemble
Difficult to make close fit between pipe and ring

Fig. 7
Same as No. 6

Fig. 8
No backing ring. No space between pipe ends before welding
Full strength maintained
Difficult to line up
Requires extreme care in depositing first layer of weld

Fig. 9
Note upset of pipe ends to inside
Appearance of form (8) after welding
Slight opening at inside not considered detrimental, as it is not a crack with sharp edges and has very little chance of causing progressive fracture

Fig. 10
Note groove cut in ring and extension of pipe ends over groove
Ends of pipe flared and upset
Full strength maintained
Easy to line up and assemble
Easy to obtain through fusion at bottom of groove and ring
Flare and upset is expensive to make and machine, although less than No. (4)

The various wall thicknesses should be prepared as shown in Fig. 3:

All high pressure lines should be prefabricated in a shop in units that could be shipped and handled, and all welds to be made at the site of erection should be limited to butt welds, preferably with the pipe in a horizontal position.

Inasmuch as most welds made at the site cannot be cleaned out after welding, it is thought that some form of backing ring is necessary to prevent the introduction into the lines of small beads of metal. These beads adhere to the inside of the pipe for a time and later loosen up and may cause serious damage to valves, turbine blading and other equipment. In shop fabrication this is not necessary as the various assemblies can be cleaned out with machine cleaning wheels. The turbines are now in use for pipes of diameters up to 20 inches and can pass around a curve with a radius equal to three times the diameter of the pipe.

Pipe units that have been stress relieved are cleaned by this method to remove tight scale and foreign matter that may be burned to the pipe wall during the bending or stress-relieving operations.

Some of the present day designs of high pressure butt joints using backing rings are shown in Figs. 4 to 10.

Our experience covering a period of over fifteen years of research in high pressure welded connections has led us to the following conclusions concerning backing-up rings:

They should not be heavy enough to cause chilling of the first layer of deposited metal.

The inside diameter of the pipe and the ring should be machined to a close fit. This will prevent arc blow and lack of fusion so common when ring does not fit close.

The ring and pipe end should be tapered to insure easy assembly and to center ring in the joint; also to compensate for variations in inside diameter of mating sections.

The ring should be solid and not split.

The inside diameter of pipe should not be restricted more than 2%.

Thorough fusion must be obtained between the ends of the pipe and ring.

Full strength based on pipe wall thickness must be maintained after welding.

The preparation of the ring and tube ends should not be expensive, and should not require special machines to produce.

The tables in Figs. 11 to 13 show the design and dimensions of ring and pipe ends that we have tested and found to comply with the above requirements:

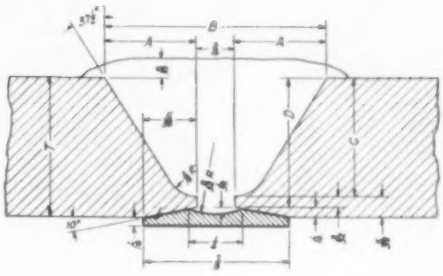
The ring is grooved in the center to a width of $^1/_4$ inch and $^1/_{32}$ inch deep. This allows the $^1/_{16}$ inch wide lip to extend over the groove $^1/_{32}$ inch and enables the welding operator to make perfect fusion of the pipe ends and ring without using excessive heat with the first layer.

This design of backing is a result of research and experimental work done in connection with the engineers of United Light and Power Engineering and Construction Company. It is considered an improvement over the one shown in Fig. 10 as no upsetting of flaring is required on the pipe ends.

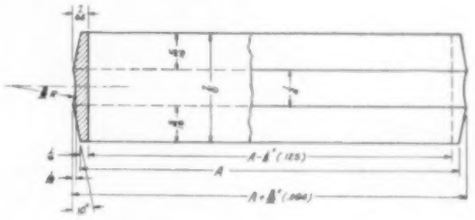
The following is a report on a typical joint tested to destruction:

The specimen consisted of 10-inch nominal pipe size Grade "A" seamless steel tubing of 1-inch wall thickness, machined and fitted with ring as shown in Fig. 13.

The welding was performed according to the Hartford approved procedure, using heavily coated electrode. After

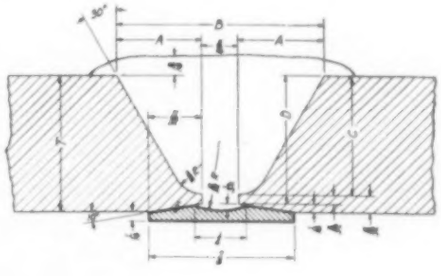


Pipe Wall T	A	B	C	D
.531	.443	1.073	.375	.468
.562	.467	1.121	.406	.500
.593	.491	1.169	.437	.530
.628	.518	1.225	.472	.565
.643	.529	1.245	.487	.580
.656	.539	1.265	.500	.593
.687	.563	1.313	.531	.624
.718	.587	1.361	.562	.655



Value of Dimension A (inside dia of pipe)

Pipe Size	Schedule No. for Wall Thicknesses (A 106-36)							
	No. 30	No. 40	No. 60	No. 80	No. 100	No. 120	No. 140	No. 160
4							5.438	3.438
5					4.563	4.563	4.313	4.313
6					5.501	5.501	5.189	5.189
8				7.625	7.439	7.189	7.000	6.813
10			9.750	9.564	9.314	9.064	8.750	8.500
12			11.626	11.376	11.064	10.750	10.500	10.126
14			12.814	12.500	12.126	11.876	11.500	11.188
16		15.000	14.686	14.314	13.938	13.584	13.126	12.876
18		16.876	16.564	16.126	15.688	15.314	14.876	14.500
20	19.000	18.814	18.376	17.938	17.500	17.000	16.500	16.126
24	22.876	22.626	22.126	21.564	21.000	20.500	19.786	19.376



Pipe Wall T	A	B	C	D	Pipe Wall T	A	B	C	D
.750	.437	1.060	.584	.6875	1.156	.671	1.530	1.000	1.093
.812	.472	1.132	.656	.7495	1.218	.707	1.602	1.062	1.155
.843	.490	1.168	.687	.780	1.250	.725	1.638	1.094	1.187
.906	.527	1.242	.750	.843	1.312	.761	1.710	1.156	1.249
.937	.545	1.278	.781	.874	1.343	.779	1.745	1.187	1.280
1.000	.582	1.351	.844	.937	1.406	.815	1.818	1.250	1.343
1.031	.599	1.386	.875	.968	1.437	.823	1.834	1.281	1.374
1.062	.614	1.416	.906	1.000	1.500	.870	1.927	1.344	1.4375
1.125	.653	1.494	.969	1.063					

All dimensions are in inches

Figs. 11, 12 and 13—Butt Welds in High Pressure and High Temperature Service Recommended for Wall Thickness $^1/_4$ In. and Greater

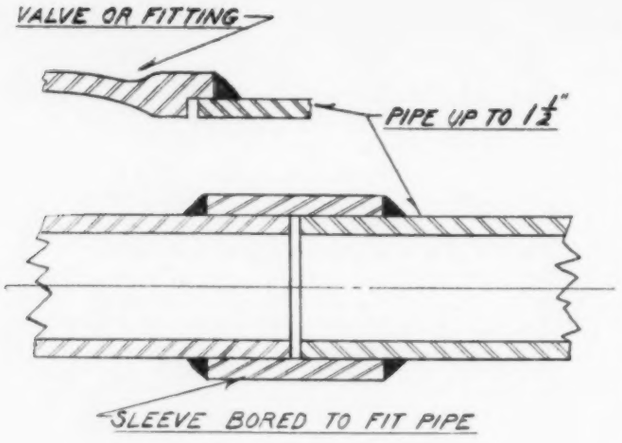


FIGURE 14

the welding groove in the specimen had been filled approximately flush with the outside diameter of the pipe, one-half of the circumference was reinforced approximately $^1/_4$ inch thick x 3 inches wide, using longitudinal weaving beads. The other half was reinforced $^1/_8$ inch thick and approximately $1^3/_8$ inch wide, using circumferential beads. The reinforcing was of the same material as used in welding the specimen.

The specimen was stress relieved by heating in a furnace to 1200° F., held for one and one-quarter hours and cooled in the furnace to 600° F., after which it was removed and cooled in still air. This stress relieving is considered equal to that which would be performed in the field under ordinary field conditions.

Tensile tests were taken next to determine the importance of the reinforcement. Two were pulled without removing the reinforcement and one was machined flush with the outside diameter and inside diameter of the tubing. All three pulled in two in the tube wall outside the weld zone at between 52,000 and 53,000 lb. per square inch of tube wall.

At first glance it would seem that with the reinforcement removed before testing that the break must come through the weld or at a point where the wall thickness of the pipe had been reduced by the tapered counter bore. Upon examination of the finished welded piece, it was found that the shrinkage of the welded specimen was in two directions; namely, a longitudinal shrinkage of approximately $^3/_{16}$ths of an inch and a reduction in diameter at the point of contact with the backing-up ring of approximately $^1/_8$th of an inch. (It should be noted that the backing-up ring was compressed approxi-

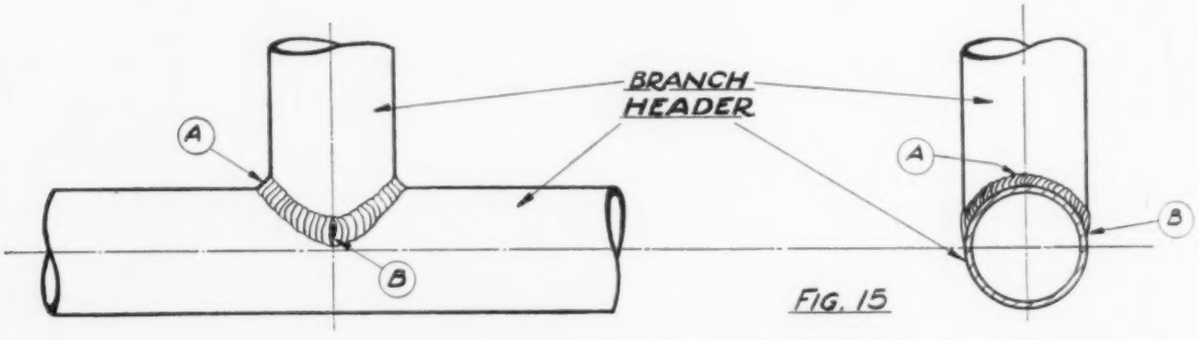


FIG. 15

TYPICAL CROSS SECTIONS BELOW ARE TAKEN AT POINTS INDICATED BY LETTERS 'A' AND 'B' ON ABOVE LAYOUT.

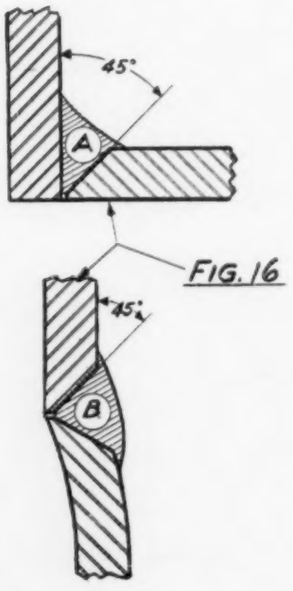


FIG. 16

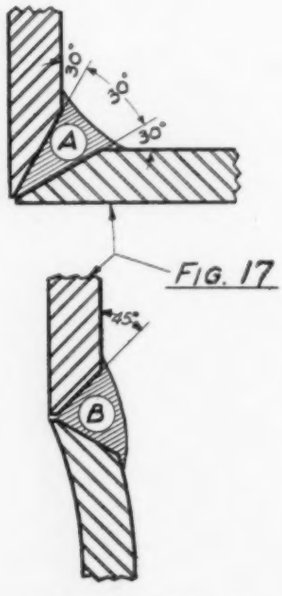


FIG. 17

FIG. 18

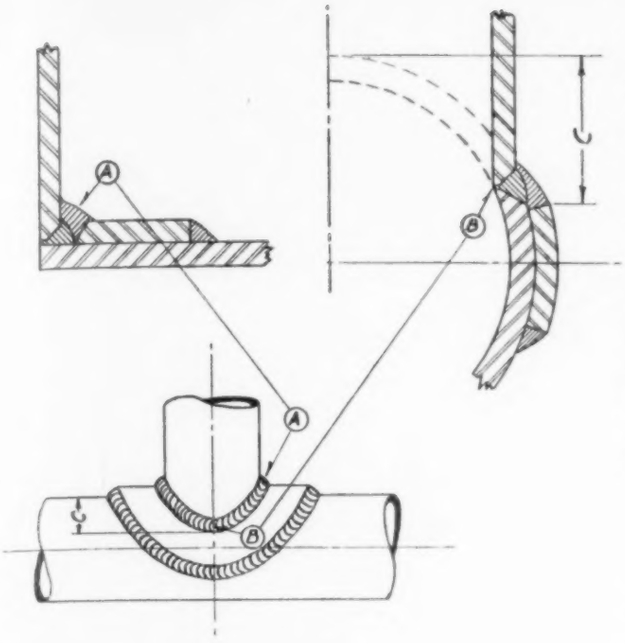


Fig. 19—Ring Plate Type. Note That Flat Portion C Is Not Reinforced

mately $^3/_8$ths of an inch in circumference without any tendency to crack the deposited metal, or without any buckling of the backing-up ring. It is also to be noted that the ring fit very closely to taper bore of the pipe after welding instead of bowing away from the pipe wall as is the case with the usual type of ring.)

The minimum for this grade of material as given in A. S. T. M. Specifications is 48,000 lb. This material as received from the mill actually tested between 52,000 and 54,000 lb. per square inch.

Free-Bend Test.—Elongation of outer fibers 40%. This test did not show any evidence of fracture and could have been carried through about 50%; however, the Code for Pressure Piping—A. S. A. B-31 calls for an elongation of 20% minimum.

Back-Bend Test.—Approximately 190 degrees. No fracture. Penetration and fusion to backing-up ring okay.

Nick-Break Test.—Grain fine, except reinforcement which is medium coarse. In welding with the proper procedure, each succeeding bead anneals and changes the grain structure of the bead below it. The stress relieving does not change the grain structure of the top bead; hence, the coarse grain structure. It should be noted that the nick-break test shows perfect sound metal without any trace of slag inclusions, gas pockets or lack of penetration into the backing-up ring. This specimen clearly shows groove in the backing-up ring completely welded and fused and a clear shear break in the junction of the ring and pipe.

Side-Bend Test (Navy Type).—This test shows amount of penetration and fusion along the sides of the welding groove. The test is comparatively new and is intended to supplement the free-bend and back-bend tests in order to show the condition of the weld at the line of fusion along the welding groove. It has been thought that in the free-bend test the deposited metal half way through the pipe wall could be of inferior quality and lack fusion, and that inasmuch as it is compressed, would not show up in either test.

As the above tests indicate that 100% strength is obtained without upsetting or reinforcing, it is thought that the amount of additional weld-metal shown in Fig. 13 would be sufficient to take care of the variables encountered in field welding.

It was not found necessary to use any spacing devise, as the taper of the ring coincides with the taper bore of the pipe to allow the proper spacing. The difference in the diameter of the ring at the smallest size and the larger bore of the pipe on the end allowed easy assembly preparatory to welding.

It was not found necessary to tack weld this pipe; however, we believe that tack welding should be done on the job to expedite erection. The need of upsetting the ends of pipe to allow for the boring out seems unnecessary, and in this connection allows the use of standard welding ells and welding fittings, which would be practically impossible to upset owing to their shape and method of manufacture.

(b) Fillet Welds

This type of weld is used in attaching slip-on and screwed flanges. The A. S. A. Code for Pressure Piping does not recommend slip-on flanges for over 300 lb. working pressure. Some of the oil refining companies are using this type of flange successfully for pressure as high as 900 lb. However, it is thought that the butt-welding flange can be applied with less distortion of the face and with less expense all things considered.

On small pipes the fillet weld is used as shown in Fig. 14.

The fillet weld is also used in attaching pedestals and

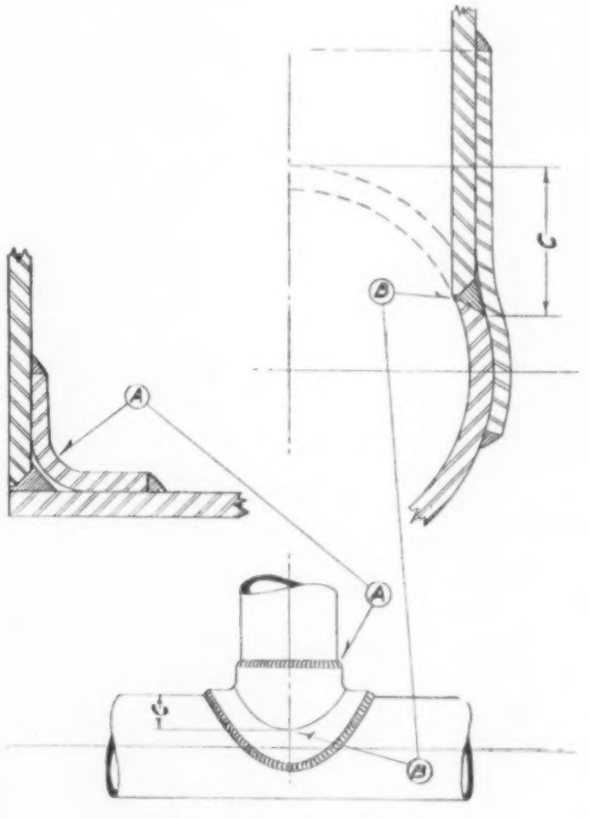


Fig. 20—Saddle Type. Flat Portion C Is Reinforced by the Ring Section of the Saddle Which Encircles the Branch

supports for headers and elbows; anchors to pipe-lines and various reinforcing members for branch intersections.

(c) Branch and Intersection Welds

The header or manifold of today is a combination of tubing and various welding fittings prefabricated by welding in the shop. In some cases the valves are welded direct to the openings during fabrication and then made a part of the piping system by welding at the construction site.

The design and execution of this type of weld is much more difficult than either the butt or fillet welds and should not be attempted in the field.

The three methods of making branch connections having the widest use are shown in Figs. 15 to 18

The first example, Fig. 16, is prepared for welding by inserting the branch flush with the inside diameter of the header. The end of the branch changes from a square cut at point *A* to a 60 degree bevel at point *B*. The hole in the header is also beveled.

Figure 17 shows that both the branch end and the hole in the header are beveled. Both methods require very careful layout and fitting in order to produce the proper welding groove.

What is thought to be a better method of preparation for a branch connection is shown by Fig. 18. In all cases when this method is used, the hole in the header is cut to dimensions of the inside diameter of the branch and parallel to the side walls of the branch. This does not require an elaborate technique. The holes for small branches can be drilled or bored, the larger sizes cut with the torch either manual or machine-guided. Considerably less material is removed from the header.

The preparation of the branch pipe end is a true development of the intersection of cylinders and can be laid out on a template and transferred to the work or cut by a machine-guided torch capable of developing this intersection. Such machines have been perfected and are now on the market. When the hand-manipulated torch is used, it is held at a constant angle with relation to the axis of the pipe. This manipulation is not as difficult as in the methods previously described and can easily be handled by the average welding operator (Fig. 24).

It should be remembered that the easier it is made for the operator to prepare the connection and deposit the weld-metal, the greater assurance we have of obtaining uniform good quality welds.

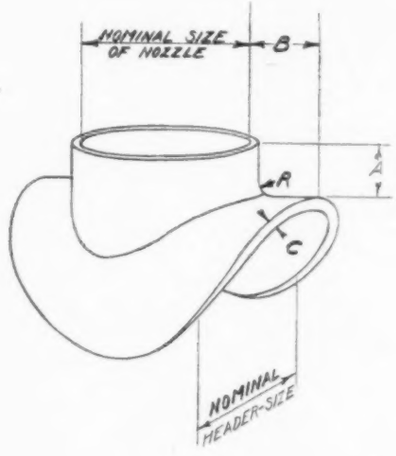
When a section is cut out of a pipe and a branch is inserted, the strength of the original pipe is impaired to a degree depending upon the relation of size of branch to header, and the relation of wall thickness to the diameter of the header section. In the design of relatively short headers with many branches, it is quite common practice to make the header wall heavier than would be necessary if no holes were cut, thus eliminating the need for additional reinforcing.

When the wall thickness is based on pressure and temperature conditions, some form of reinforcing the branch connection is necessary. Where the branch pipe diameter is one-third, or less, than the diameter of the header, it is thought that the addition of weld-metal properly applied would act as a reinforcing ring. As the size of the branch increases in relation to the diameter of the header, additional reinforcing is required.

As the design approaches size on size (12-inch branch to a 14-inch header), the flat portion at *B*, Fig. 15 must be considered. The increased cross-sectional area at this point concentrates a greater strain at point *A;* and if pressure is raised to the bursting point, rupture will always occur at this point. The use of gussets or flat ribs between the branch and header have not proved satisfactory and have been replaced with a ring or saddle.

Fig. 21

Nominal Size of Nozzle	Nominal Header Sizes	*A*	*B*	*C*	*R*
2	2 to 24	1 1/4	1 3/4	1/2	1/2
2 1/2	2 1/2 to 24	1 1/2	1 3/4	1/2	1/2
3	3 to 24	1 3/4	2	1/2	1/2
3 1/2	3 1/2 to 24	1 3/4	2	1/2	1/2
4	4 to 24	2	2	1/2	3/4
5	5 to 24	2	2	1/2	3/4
6	6 to 24	2 1/4	2 1/2	1/2	3/4
8	8 to 24	3	3	5/8	1
10	10 to 24	3 1/2	3 1/2	5/8	1
12	12 to 24	4	4	5/8	1 1/4
14 O.D.	14 to 24	4	4	5/8	1 1/2
16 O.D.	16 to 24	4	4	5/8	1 1/2
18 O.D.	18 to 24	4	4	5/8	1 1/2
20 O.D.	20 to 24	5	5	5/8	1 1/2
24 O.D.	24	5	5	5/8	1 1/2



The ring type can be made without the use of dies and can be cut and rolled or shaped to the header in the field. For this reason the ring type is advocated by some engineers. However, reinforcing saddles can be obtained from stock of several manufacturers in the sizes given in the following Table. The cost of the finished assembly will compare very favorably with the ring plate type (Fig 21):

The ring portion of the saddle not only supports the flat section of the connection, but it also tends to relieve the weld of concentrated strains set up by movement of the connecting branch line caused by expansion and contraction, or so-called hammer shock.

Where the ring or saddle is applied to assemblies which are to be later stress relieved or annealed, a small hole should be drilled through the reinforcing member to relieve pressure that may build up due to expansion of entrapped air or gas. Serious deformations have been observed in large diameter pipes when this precaution was not taken.

Figures 25, 26 and 28 show typical examples of branch connections reinforced with saddles, as well as stock fittings used to make up the desired assemblies. Figure 25 has a branch connection directly in the side of a welding ell and the saddle is shaped to fit the ell.

Figure 27 shows the method of providing a base to support the 12-inch ell and riser pipe.

Another design of branch connections that is proving

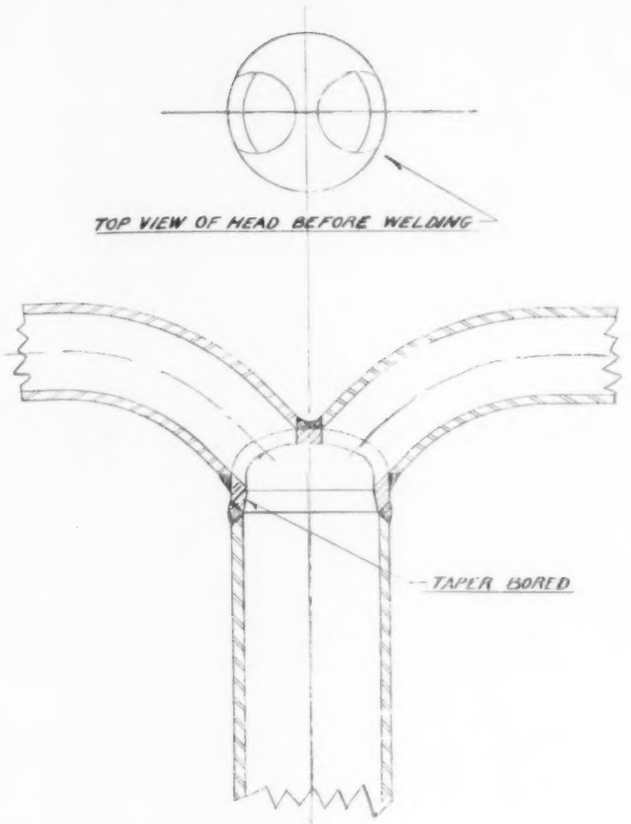


FIGURE 22

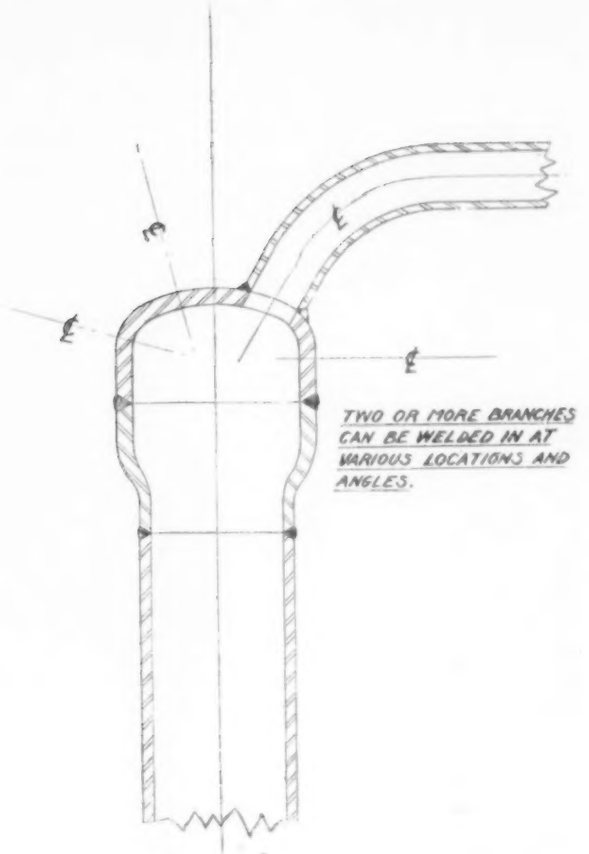


FIGURE 23

quite successful for high pressures and temperatures is made by welding two or more branches into a welding head. The head should be of heavier wall material to compensate for the reduction in strength of the openings.

It has been stated earlier in this paper that high pressure piping should be prefabricated in a shop as much as possible in order to obtain the quality required. The shop has the following advantages:

Trained personnel steadily employed in the research, design and supervision of this class of work.

Equipment designed especially for pipe fabrication.

Special machines and welding operators continuously employed for high pressure fabrication.

Figures 29 to 37 are shown to illustrate some of the equipment and methods used in our shops, also to show typical examples of fabricated piping used in Power Plants, Oil Refineries and Industrial Plants.

Figure 29—A large header during the process of welding the branch connections. This work is supported by the rollers in the foreground and revolved by a machine so that the weld is made in a downward position. The operator is controlling the revolving machine with a switch operated by his left foot. Note that the saddles are slipped up on the branch pipes. The saddle for the large opening is left off as it would interfere with the pressure weld. It is later put on in two sections and welded.

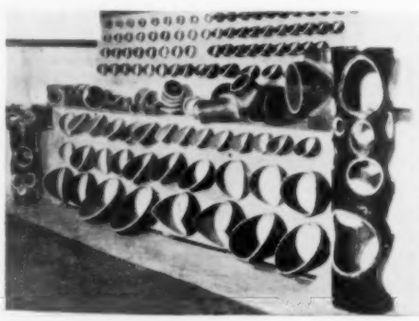


Fig. 24—Examples of Various Intersections Developed and Cut by Guided Torches

Fig. 25—Branch Connection in Side of Ell

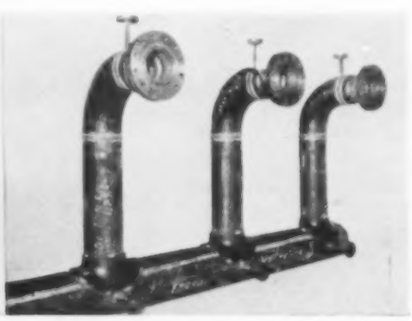


Fig. 26—Typical Branch Connections Reinforced with Saddles

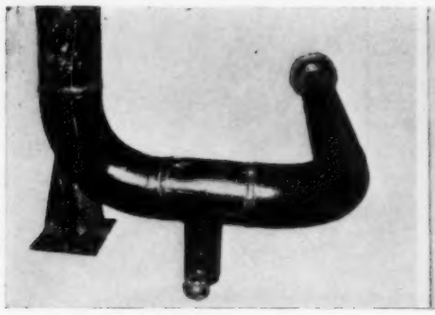


Fig. 27—Method of Providing Base to Support Ell and Riser Pipe

Fig. 28—Typical Branch Connections Reinforced with Saddle

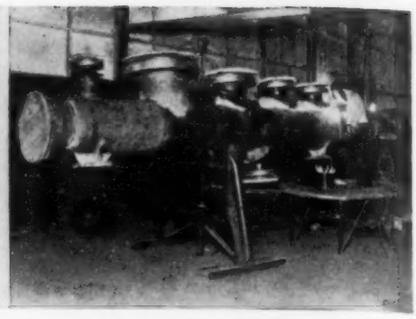


Fig. 29—A Large Header During the Process of Welding the Branch Connections

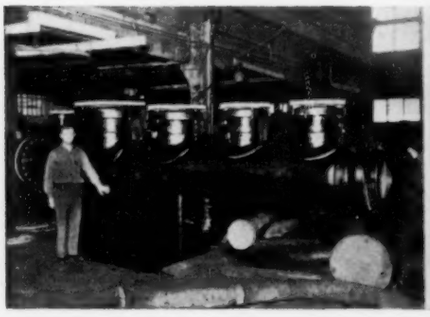


Fig. 30—The Finished Header with the Large Supporting Base Which Also Serves as an Anchor for the Line. Note the Small Base at the End Which Finally Rests on Rollers to Allow for Expansion of the Header

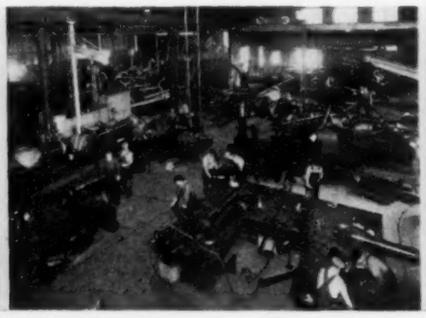


Fig. 31—A View of the Department Where the Various Tubes, Bends and Fittings Are Layed Out, Fitted, Assembled and Tacked Preparatory to Welding. The Layout Tables Are of Heavy Cast Iron and Machined True. All Are Set at the Same Height to Accommodate Large Assemblies

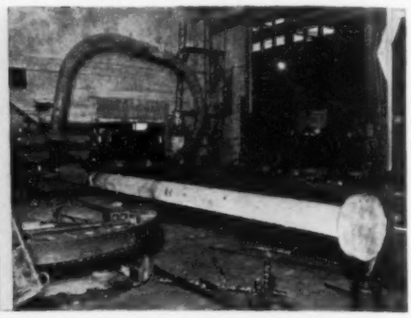


Fig. 32—A Large Main Steam Pipe to Turbine Composed of 70 Feet of 10-Inch Tubing with 1-Inch Wall Thickness Fabricated and Shipped in One Piece with No Field Welds

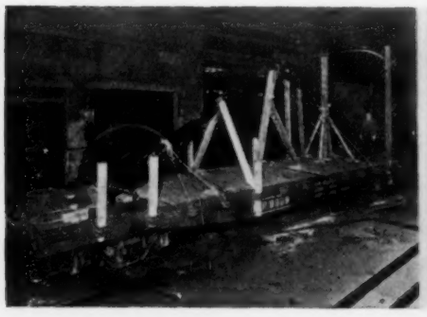


Fig. 33—The Same Piece Loaded and Ready for Shipment

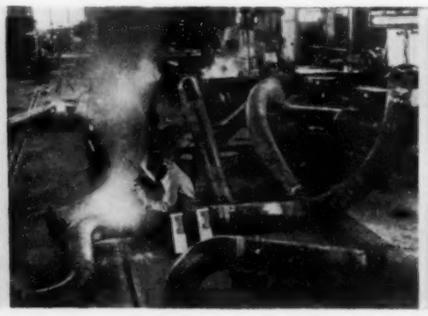


Fig. 34—Positioning Pipe to Facilitate Welding

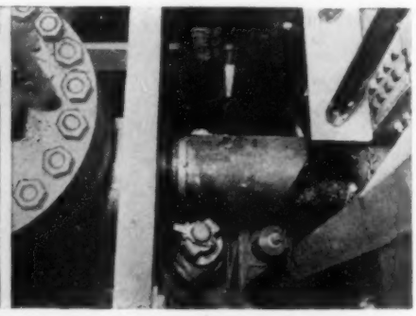


Fig. 35—Example of Difficulties Encountered in Pipe Welding

Fig. 36

Fig. 37

Position Field Welds

QUALITY OF WELDS

The method of evaluating the quality of welding has been the subject of much discussion and research. The X-ray and other methods of non-destructive testing have not proved practical for piping work, especially on welds made in the field. The results of research in our own shops have convinced us that the quality of welded joints can be determined by the specific process used and by the ability of the operator to apply that process. Predictable results as to the physical properties and soundness of such joints can be secured only by strict adherence to a fixed procedure of welding which has been properly investigated. It cannot be expected that good results can be obtained even by careful and painstaking operators if poor materials, inadequate or worn-out equipment are used, or if fundamentally improper methods are pursued; nor can the purpose of welding be attained by the mere adoption of a carefully outlined

process of welding if the operators are not adequately trained to follow that process and properly supervised to be certain that all essential details of the specific procedure are followed.

In pressure pipe welding, the physical properties of the weld-metal, such as tensile strength and elongation, are determined by the particular process of welding that is used. The reliability of the welded joint is determined by the degree to which that weld-metal is kept free of foreign materials, such as slag or gas pockets, and upon the degree by which it is fused to the base material. Under a fixed procedure of welding, these two latter factors are the only ones over which the operator has control. We do not consider it necessary, therefore, to test every operator for tensile strength and elongation.

It is our belief that the first step in welding must be the adoption of a procedure of welding in which all essential variables are fixed within definite limits. This procedure is then investigated to determine whether it will produce welds with the desired physical properties. The test required for an operator is included in the investigation of a welding process, because there have been many instances wherein failure to obtain results has been attributed to the inability of the operator, when the difficulty lay in the fundamentals of the process. Having established that a given process is satisfactory, we need only to test the operator to determine if he has the ability to follow that process.

Naturally the process used in making field welds in various positions and under cramped conditions will be different than that used in the shop; and when investigating and determining a field process, conditions in the field should be duplicated.

Figures 36 and 37 are examples of field welds made with the tubing in a vertical position and with the tubing in a horizontal position, respectively. The size of rod, voltage and amperage as well as the number of beads would be entirely different in each of the examples shown.

In Fig. 34 the pipes are not revolved in a machine, but can be so positioned on a floor so as to make welding much easier than a condition in the field such as shown by Fig. 35. This is a view of a piece of tubing welded to a valve body and the view is shown looking straight down on the work. This view clearly shows the obstructions and difficulties encountered by the welding operator.

The author fully realizes that there may be other designs and methods of welding that will meet the desired requirements, and this paper is given with the hope that it will at least bring out some new points and raise some questions that will in the long run help to advance the art of welding.

A Facing Better Than New

By G. D. RUSHING†

Reclaiming Trolley Shoes, Brakeheads and Overhead Frogs and Crossovers

READING of the half-soling of rails and special track work by the welding process to add life and postpone renewal of expensive track work in pavements leads me to explain how we are increasing the life of our trolley shoes, brakeheads, overhead frogs and crossovers, by hard facing and refacing with the acetylene torch and proved hard-facing metal rods.

In these days when trolley and bus lines must economize in every possible direction, we are constantly investigating and testing for methods and processes which will cut down our rate of renewal of parts that wear out, in the operation of trolley cars or trackless trolleys. Take our trolley shoes used on our trackless trolley buses, when we have reached the limit of wear of the new shoe, we refill or resurface the contact groove with proper proved metal rods applied with the acetylene torch. We grind shoe then to proper contour which burnishes and polishes, restoring an appearance as good as new. For durability or service, we gain a life from this reclaimed process of two to three times longer period than on the original standard surface supplied by the manufacturer.

This reclamation may be repeated many times. After checking cost of welding material and labor, we find at least 75% saving of the first cost of new shoe on every shoe so reclaimed. We have been doing this since 1931, and in that time have not thrown away or obsoleted more than 75 shoes. The metal rods, or special surfacing material must provide good ductility with a close grain and be very hard and give a superior finish when ground or polished, giving the unit so treated, or refaced, a new-like appearance.

In the case of our brakehead, we grind down the new brakehead at the shoe contact point about $^1/_8$ inch; we then build back to a little above the original surface with a hard-facing metal applied with the acetylene torch and then grind back to fit tight. This refaced new brakehead lasts from three to four times as long as if we were to install the original shoe as supplied by manufacturer. This hard facing build up of the contact prevents the shoe from rattling around in the holder which always produces excessive wear.

Likewise on our overhead frogs and crossover units on our trolley wires, we have been reclaiming or refacing and reconditioning them, using the acetylene torch and the same metal as on the trolley shoes. Again this reclamation or resurfacing can be repeated several times, or until some new design or requirement of the line obsoletes these units we have reclaimed. As in the case of the trolley shoes, this new facing gives a life or added service from these parts two to three times that of the unit as is originally supplied by the manufacturer, but beyond that the additional repeated resurfacing gives more life. Each refacing only costs about 75% of the price of a new unit.

† Supt. Power & Equipment, Shreveport, La. Railway.

HOW TO METAL SPRAY*

By J. G. MAGRATH†

FOREWORD

IN THE past much has been said and perhaps too much written covering Metal Spraying. The fact that metal can be sprayed has been widely advertised and is well known. "How to do it?" and "What to do it *on*?" are questions that seem to have been either vaguely answered or actually evaded, probably due to an extraordinary lack of practical knowledge of the subject. Metal spraying is in no sense the universal cure-all as often represented. There is, however, a definite field wherein certain mechanical conditions and problems are most satisfactorily solved with metal spraying. We will outline the operations necessary for the standard proved applications, that have been found both successful and economical.

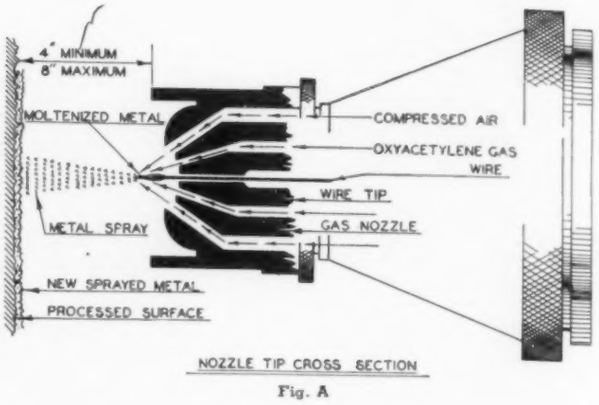


Fig. A

THE PROCESS

Ordinarily a light-weight portable metal spray gun which may be fixed in position as required, is employed. Four supplies are necessary; metal wire, oxygen, acetylene and compressed air. (See Nozzle Tip Detail Fig. A.) A compressed air driven turbine propels a series of speed reducing gears which feed the metal wire at uniform speed into and through a nozzle, to the tip where an oxyacetylene flame moltenizes the metal wire and compressed air atomizes the molten metal, blowing the resultant metal spray upon a surface that has been properly processed beforehand by cleaning, roughening and building up the new metal surface to any desired thickness.

THE STRUCTURE

Sprayed metal is built up in structure by the interlocking and partial fusion of minute molten metal particles projected from the spray gun. The particles are of globular form when ejected from the moltenizing area and upon impacting the surface, they flatten (pancake), shape themselves to the contour of the roughened surface and form an interlocked, keyed mass of stratified layers. This new metal is partly pervious. Voids in the stratified structure exist due to the presence of oxides and absorbed gases. While each particle or droplet may be comparable to cast metal in its characteristics, the elongation and ductility, as well as the tensile strength of cast metal, no longer prevail in the mass. The qualities of compression, wear resistance, hardness, corrosion resistance, heat and electrical conductivity will still exist to sufficient extent to answer the purposes for which the process is recommended. Sprayed metal deposits cannot be considered on applications where they will be subjected to sharp impact, rugged abrasions, continued poundings or edge strain. But when subjected to continued vibration, with full bearing surface, such as on crank-shafts, the process is satisfactory.

PREPARING SURFACES

The proper preparation of the base metal results in a foundation that enables the metal spraying deposition to "key" itself to the parent body, therefore the adherence is due to its "mechanical bond." To obtain this bond, flat surfaces are blasted with angular steel grit, sharp Cape May sand, or Joplin grit, as sharp cutting edges must be employed. When blasting, the blast nozzle is held at different angles to the surface to develop under-cut caves and over-hanging crags, (Fig. 1) which act as keys and anchorage for the new built-up slab of metal (Fig. 2).

PROPER PRECAUTIONS

When surfaces have been prepared for metal spraying they must be kept clean from grease or dirt. The area that is prepared for metal spraying is not handled with the hands. When necessary to handle, clean white cotton gloves are used. Not more than eight hours is allowed to elapse between the metal spraying operation and the blasting operation in clear weather, and not more than two hours in damp weather. Otherwise, oxidation will partially destroy the ability of the new metal to bind to the base. Blasting is never conducted outside in damp or wet weather.

SHIELDING

In sand or grit blasting all parts that are not to be metal sprayed are shielded. Due to the high air pressure used in blast cleaning, both sand and steel grit penetrate into every crevice and deeply score most

*Presented as Lecture No. 10 of the New York Section Lecture Course at Polytechnic Institute of Brooklyn.

†Applied Engineering Dept., Air Reduction Sales Co., New York, N. Y.

surfaces. Areas are shielded with a rubber adhesive tape or cloth similar to that used by stone cutters. Shafts are shielded with friction tape.

CORROSION RESISTANCE

The use of the metal spraying process has often been over-zealously promoted as the cure-all for corrosion problems of varied nature. Without becoming involved in the technicalities of preference for the use of one metal as against another for specific purposes, we will detail the mechanical operations necessary to insure success of the application after the choice of metal has been made.

Of that portion of the industry devoted to corrosion resistance fully one half of the work is done in the field. Subjects exposed to the elements are never sprayed during bad weather. Very damp days result in the compressed air lines being overloaded with moisture, causing prolonged interruptions in the spraying period. During wet weather, it is impossible to metal spray.

In spraying for corrosion resistance, the most important part of the process is the bond. Extreme care is exercised in preparing the surfaces of vessels, tanks, pipes or any surfaces. The nature and shape of the objects is generally such that only blast cleaning with angular steel grit, Joplin grit or sharp sand may be employed. Blast at different angles, thoroughly, keeping surface free from all foreign materials. The surface is not touched with the hands but is kept dry and metal sprayed within eight hours in clear weather and within two hours in damp weather. It is seldom necessary to cool the subject inasmuch as a rule, the area is of such size to allow a broader range in covering with the spray gun so that one area has an opportunity to cool while another area is being sprayed. As almost in all instances, metal spraying for corrosion resistance is an operation wherein the metal spray gun is hand propelled, we exercise careful control over the manual operation. A distance of not more than eight inches between the gun nozzle and the subject is maintained. In addition the nozzle is always directed full force to the work and not allowed to sway from side to side after the manner of a paint spray gun. On large subjects strike off imaginary blocks of about 30 inches square and first fully cover with sprayed metal the one imaginary block moving the gun in a left to right direction and vice versa. After full coverage, move the gun in an upward and downward direction again covering the full area. Next proceed to the adjacent imaginary 30 inch square block and duplicate action while former block is cooling. On completion return to the former block and repeat the procedure until the proper thicknesses over all areas are developed.

As a rule the natural finish of metal spraying applied over a blast cleaned surface is satisfactory for corrosion resistance application. When required the metal sprayed area may be wire brushed, surface ground, buffed or polished. We take care in following the ordinary procedure for the operation to insure against overheating the surface as such will cause metal coating to expand, and break its bond to the base.

MASS COATING

Where small parts such as bolts, nuts, brackets, scrap iron, angle irons, pipe fittings, handles, pins, etc., can be handled in production, such are metal sprayed efficiently and economically in a mass coating machine. This machine is very like the ordinary tumbling barrel used in metal cleaning and plating. An air exhaust removes all excess dust as well as fumes. The metal spray gun is affixed at the edge pointing into the barrel which revolves, but tumbling the contained parts continuously. Eventually every area of the part has been exposed to the metal spray. Zinc has been found the most satisfactory metal to use in this operation. The parts may be ball-burnished or rumbled in leather scrap before removal if such is desired.

HEAT RESISTANCE

Wherever iron or steel is exposed to high temperatures, hot flue gases or open flame, deterioration of the metal is rapid or the deposition of soot and clinkers seriously reduces combustion efficiency. To a great extent we correct this condition by "alumetizing." Confusion exists concerning this process. Merely spraying with aluminum does not alumetize an object. Other operations are necessary, including the most important of all—heat treating. The rules that we follow for alumetizing are as follows:

1. Prepare the object to be treated by blast cleaning with sharp grit or sand.
2. Metal spray with 99 per cent plus pure aluminum. On steel we build up a thickness of 0.006 inches and on cast iron a thickness of 0.008 inches.
3. The subject is then brushed with or dipped into a solution of sodium silicate (water glass). It is allowed to dry and then given a second brushing or dipping. It is again allowed to dry.
4. A radiant heat furnace (indirect flame) is brought up to a temperature of 1850° F. The part is then inserted in the furnace and left in approximately ten minutes. It is then removed.
5. Placed in an area, carefully shielded from a draft which might set a strain and allowed to cool to room temperature.

We have now formed an alloy between the aluminum in the steel or iron resulting in an efficient heat resisting surface.

Occasionally the presence of free graphite which has a deteriorating effect upon an iron aluminum alloy will make the alumetizing of cast iron of such nature, uncertain. Should silicon also be present a similarly unfavorable effect results inasmuch as silicon tends to hasten a decomposition of the cementite in the cast iron, leading to formation of graphitic carbon.

NON-METALLIC BASES

Of that section of the industry using the metal spray process for non-metallic bases, the carbon industry is by far the most consistent user as well as the largest of oxygene and acetylene. The ends of the carbon resistors are sprayed with a thin film of copper or brass. No preparation of the surface before spraying is necessary, the natural texture of the carbon being an ideal receiver. Copper wire is then wound around the sprayed surface and soldered, thus providing a permanent connection. Large intricate production machinery has been designed to handle this operation. Some of these automatic equipments produce 20,000 carbons per day.

In the glass industry the process is employed chiefly for providing a reflecting surface to objects such as lamp bulbs, button reflectors and other subjects. The glass is heated to within close range of its plastic state providing a condition allowing embedment of the metal particles projected from the spray gun. Aluminum is generally accepted as being the best metal for this purpose.

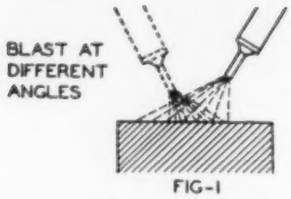


FIG-1

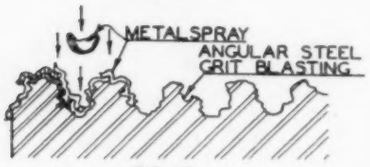


FIG-2

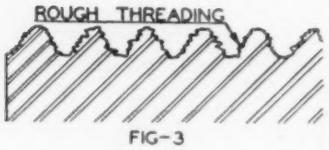
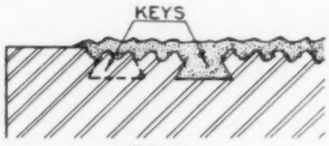


FIG-3



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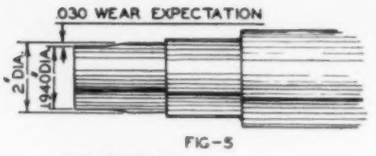

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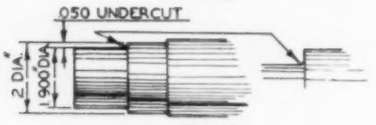


FIG-6

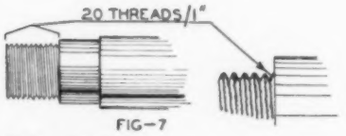


FIG-7

FIG-8

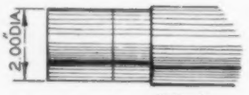
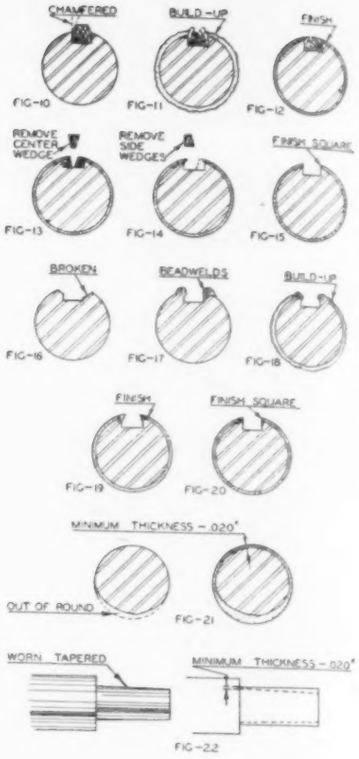


FIG-9



In metal spraying paper and cloth, both must be free from oil surfacing. In addition we hold the spray gun as far back as 18 inches away from the object, at the beginning, to prevent scorching. After sufficient metal has been deposited, the gun can be brought within close range. Only the soft white metals will adhere to the initial coating. Should the finished coating required be brass, copper or bronze, or possibly steel, iron, nickel or monel then an initial coating of one of the white metals, namely, tin lead, zinc or babbitt, must be first applied to provide a base for the harder, higher melt point metal.

The same rule applies to spraying plaster resin and wood bases. If very hard, these may require a light sand blasting in preparation. They all must be absolutely dry and free from moisture before spraying or else the metal coating will lift and peel. In every case where a hard metal is to be the final surface, an undercoat of soft white metal must be first provided.

BUILDING UP

The operation of restoring dimension to worn parts is known to the industry as "Building Up." It offers a very large field for the metal spray process. Expensive machine parts, turned shafts, crank-shafts, shafts of armatures, turbines, transmissions, impellers, conveyors, stokers, brake cams, worms, jacks, propellors, wheel spindles, piston rods, pump rods, axles, valve stems, studs are built up to their original dimension on the wearing, bearing or journal surfaces. Rolls of many types for dryers, printing presses, food presses, hydraulic rams, pistons, cylinders, are resurfaced. Patterns, molds, slides and flats are restored to their original dimension. In the case of round shapes the majority are mounted on the lathe and in such instances blast cleaning is not always required.

ROUGH THREADING

Cylindrical objects such as shafts, studs, rods, spindles, etc., are often given a roughened surface by rough threading instead of blasting (Fig. 3). The threading tool is set well below center so that a torn thread is obtained. Threading is extended for the full length of the surface to be built up and where advisable crossed right and left across the same area. All loose or partially loose particles are roughly filed off without disturbing the roughness of the threading. No particle or sliver is allowed to extend through the new built-up metal.

LARGE CYLINDERS

Large cylinders and the like where metal is to be built up on the inside are rough threaded and grit blasted or very rough machined and grit blasted. When the nature of the work so indicates, the base metal is "keyed" (Fig. 4). These keyways are spaced as often as may seem advisable and are turned completely round the inside diameter. They are only employed where they will not seriously weaken the structure of the base.

CAPABILITY

Parts of considerable value are salvaged for a small fraction of their original cost, and provided with a new surface that, in most instances, is superior to the original as we build up a low carbon content part with a higher carbon content metal surfacing, and give longer wearing life. One large motor bus transportation company receives $1\frac{1}{2}$ or 2 times the wear from the metal sprayed built-up surface on their crank-shafts than they received from their original surface. Sprayed metal has greater surface porosity than ordinary metal and the thousands

of minute, surface air cells naturally become an equal number of minute oil bearing cups or pockets. In addition, we are able to build upon any base metal with any other surface metal that is deemed advisable. No excessive heat is applied to the part which is being built up, therefore no injurious stresses are set up. Bearing surfaces of an armature shaft may be built up without stripping or rewinding. There is no danger of distortion or damage.

SELECTION OF METAL

The first step in building-up a part, is to select the new metal. This is controlled in many instances by the machine shop facilities available. We are guided by the following rule:

On steels of higher than 0.40 carbon content, wet grinding must be employed. The surface becomes too hard to be treated otherwise. Steels of 0.40 carbon content or lower, may be tooled. Monel, nickel, nichrome, ingot iron, copper, brass and all of the bronzes, may be tooled. Naturally in all metal wet grinding renders a superior finish to tooling. In metal spraying carbon steels, the carbon content of low-carbon steel is slightly increased; the carbon content of medium carbon steel is maintained; the carbon content of high-carbon steel is slightly reduced.

OPERATIONS

In metal spraying a shaft, spindle or similar part we perform five major operations.

SETTING UP

The first operation called "setting up" consists of mounting the part on the lathe, measuring the wear and determining the amount of metal to be removed, if any, to provide the proper base, taking into consideration the wear expectation of the shop. In every shop machine parts will wear to a certain extent before they are either replaced or restored to size. This is termed "wear expectation" (Fig. 5). Regardless of what this wear may be, provide an additional under-thickness of sprayed metal which is called the "foundation," of at least 0.020 inch in thickness. Therefore, assuming that the shaft had worn 0.030 inch on the radius, add 0.020 inch for the foundation, giving a total of 0.050 inch on the radius.

TURNING DOWN

The second operation is called "turning down" (Fig. 6). With the shaft set in the lathe and centered, turn down the area to be metal sprayed to 0.050 inch below the finished dimension. Set the cutter slightly below center so as to make as rough a turn as possible.

ROUGHENING

The third operation is "roughening." The surface developed by turning is not adequate. Roughen either by blasting the surface with steel grit or by rough threading (Fig. 7). In the case of rough threading, we ordinarily use between 16 and 24 threads to the inch and set our tool well below center, cutting and tearing as rough a thread as possible for the full length of the surface Remove all loose slivers or particles and keep the surface clean.

METAL SPRAYING

The fourth operation is "metal spraying" or "building up." A partial duplicate ridging of the thread texture will be carried along with the build-up. This texture evens out fairly well after building up about 0.020 inch above the tops of the threads (Fig. 8). For wet grinding build up 0.020 inch above the finished dimension on the radius. For turning build up 0.030 inch. 0.020 inch is sufficient to allow enough metal for grinding and obtain a nicely finished surface. In turning, it is necessary that we provide sufficient metal to obtain both a rough cut and a fine cut and also allow for draw filing if required. Do not allow the part being metal sprayed to develop a temperature much greater than 250° F. This is determinable by lightly touching the part being sprayed with the back of the hand. If so hot that leaving the hand momentarily against the part is not possible, then we stop spraying and allow the part to cool to a degree where we can allow our hand to rest against it without discomfort. Excessive heat causes the sprayed metal to expand and pull away from the base. Wherever possible mechanically cool the surface by playing a compressed air line upon the opposite side of the part which is being sprayed. This air is passed through the water and oil separation system provided with the metal spray apparatus as it must be free from oil and water. The Metal Spray Gun is affixed to the lathe carriage tool post either singly or in multiple or, if necessary, it is held in the hand. Keep a distance of not less than four inches nor more than eight inches between the nozzle and the part being sprayed, and project the nozzle directly to the center of the shaft holding at right angles to the shaft length so that the full force and benefit of the metal spray blast is received. The part that is being built up turns on the lathe downwardly and toward the Spray Gun at a maximum speed of 40 feet per minute. Spray evenly from left to right or vice versa. The work is calipered as it progresses to assure evenness of deposition and to avoid depositing excessive metal. Where there are threads, teeth or any portion of the parts requiring protection immediately adjacent to the area that is being metal sprayed, such areas are protected with ordinary friction tape. Metal spraying will not adhere to areas which have not been properly prepared beforehand.

Fig. B—Many Locomotive and Railway Car Machined Parts as Well as Electric Street Railway Car and Motor Bus Parts May Be Restored to Original Dimension. Shown Are Inside Pump Plungers, Outside Pump Plungers, Feed Water Pump Pistons, Throttle Stems, Cross Head Wrist Pins, Headlight and Coach Light Generator Armature Shaft. All of These Are Quickly "Built Up" to Size on the Lathe

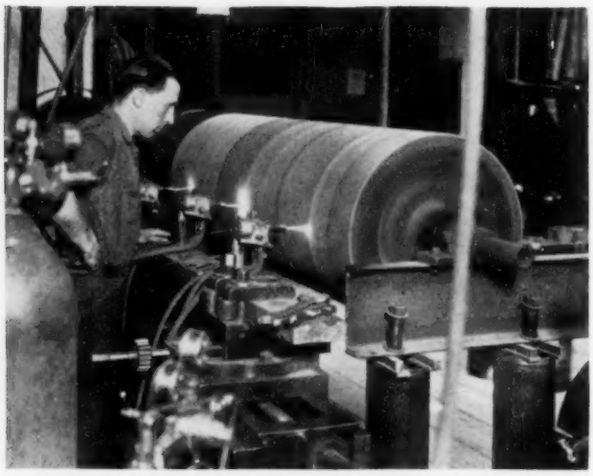


Fig. C—Cast-Iron Hydraulic Ram, 5 Feet Long Was Badly Scored. After Steel Grit Blasting It Was Resurfaced with Metal-Sprayed Bronze and Ground to New Oversize Diameter

FINISHING

The fifth operation is "finishing" (Fig. 9). If the part is to be wet ground then both the part and the grinding wheel should turn in toward each other. We seldom allow the surface speed of the wheel to exceed five times that of the part and ordinarily use a 60 grit carborundum wheel in the proper size to fit the lathe and the job, with a wet grinding compound of vegetable base, flowing in a steady stream of sufficient volume to wash off the grindings. A vegetable base grinding compound leaves a protective film on the working surface and retards any tendency to oxidize.

If it is intended to tool the part as when low-carbon steel is used, then tool with a sharp diamond point taking a slow fine cut. If additional finishing is necessary, as for slight tapers, etc., lightly draw-file. If a high finish is required, use wettened emery.

KEY WAYS

When key ways are encountered the character of the shaft and the function of the key determines the procedure. Where there is little torque and the key way is square and without damage insert a hard wood block (or carbon) for the full length of the key way (Fig. 10). Allow the block to extend well above the surface of the proposed metal spraying and chamfer the vertical side in order to allow the metal spray to contact the innermost corners. Then build up the metal to the required dimension (Fig. 11). The subject is ground or tooled leaving the block in position and working through it (Fig. 12). After having obtained our dimension we carefully remove a "V" wedge from the center of the wooden key way for its full length (Fig. 13) then carefully remove the remaining side wedges (Fig. 14) and finish the overhanging edges square with the key way (Fig. 15). If the edges of the key way are broken down, (Fig. 16) such indicates that there is considerable strain on the edge of the key way due to either sudden braking or other harsh handling. In this case build up the edge of the key way with a bead weld (Fig. 17) obtaining a fusion at this point of greatest strain. The balance of the surface is roughened and built up with sprayed metal (Fig. 18) finally finishing as above outlined over the entire surface (Fig. 19) and finishing the inside of the key way square (Fig. 20).

UNEVEN WEAR

At no time do we allow a built-up thickness of *less* than *0.020 inch*. If the part is worn on one side more than the other, take measurements from, as well as determine the thickness of our build-up upon the side that is least worn. Build up the side that is most worn first to approximately a true round, by holding the part stationary in the lathe and building up on the low area only (Fig. 21). After having sufficiently "trued," revolve the part and metal spray the entire circumference evenly. This same ruling applies when parts are received that are worn to a taper length-wise (Fig. 22). A minimum thickness of 0.020 inches *must* be maintained.

CYLINDERS, ROLLS, ETC.

Excepting that the scale is greater and that blasting with steel grit may be necessary in addition to rough threading, the same procedure followed in building up of shafts, spindles and rods, is applied to cylinders, cylinder liners, rolls, drums and the like (Figs. 23, 24 and 25).

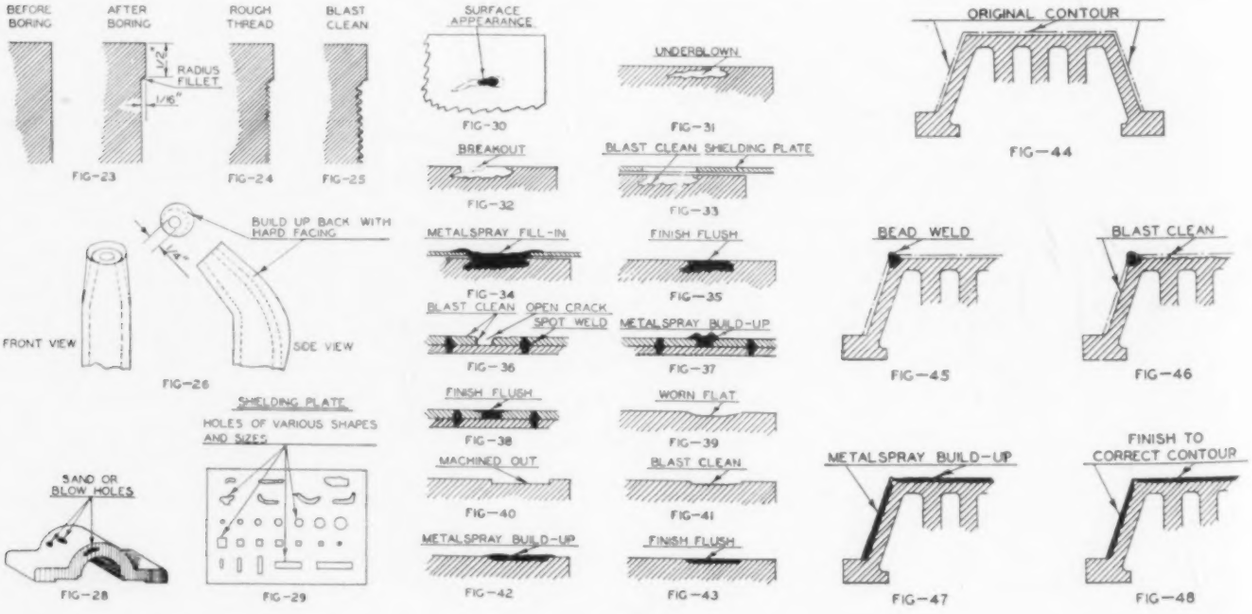


Fig. D—Worm Shaft of 0.35 Per Cent Carbon Content (Hardened Screw) "Built-Up" on Bearings with 0.80 Per Cent Carbon Steel on the Lathe with Metal-Spray Process and Wet Ground to Finished Diameter

Variation is required in the choice of metals as cylinder walls and pistons are always of different metal. If a cylinder wall is of cast iron, then we will build up the piston with high-carbon steel. If the cylinder wall is high-carbon steel we build up the piston base with low-carbon iron. No higher than 0.80 carbon content steel for facing pistons or lining cylinders is used as steels of higher carbon content tend toward embrittlement.

FILLING IN

Defects such as blow-holes, sand-holes, gas-holes in iron, steel, bronze, aluminum or other metals, may be filled in with the metal spray process. In the case of castings containing sand or blow-holes (Fig. 28) first make a metal shielding plate with various size holes cut therein as well as shaped (Fig. 29). The nature of a sand or blow-hole is very often such that the superficial hole appearing on the surface becomes greatly enlarged beneath (Figs. 30 and 31). Therefore, when such is found to be the case, break the top skin and expose the full area as much as possible (Fig. 32). Protecting the balance of the surface with the metal shield, blast clean the accessible area of the hole (Fig. 33) and fill in with sprayed metal taking care not to overheat (Fig. 34). This shield is removed and the surface is ground flush with the base object (Fig. 35). Filling in of crevices and cracks is done in like manner (Figs. 36, 37 and 38).

Fig. E—Motor Truck Differential Side Case Casting. Faces Blasted with Steel Grit, "Built-Up" on Lathe with 1.20 Per Cent Carbon Steel by Metal Spraying, and Wet-Ground to Exact Dimension

POROSITY

Often we find porous conditions in castings of different metals, particularly cast iron. This problem is solved by metal spraying the casting completely with approximately 0.010 to 0.012 inch of zinc, after fully blast-cleaning the part.

FLATS, SLIDES

Depressions in slides and flats which are encountered in the maintenance of wrapping, packaging and automatic machinery are filled in by treating similarly to the ordinary mechanical build-up (Fig. 39). The area that is worn is machined out to at least 0.020 inch below the depth of greatest wear (Fig. 40). It is blast cleaned (Fig. 41) and sprayed with the proper metal to about 0.020 inch above the finished dimension (Fig. 42). This surface may then be ground flush (Fig. 43). As a rule, where allowable, a filling-in metal that is harder than the base metal is used to provide longer life.

DIES, MOLDS, METAL PATTERNS

Especially in the forming of sheet metal with dies, the forming edges of the dies are subjected to considerable edge strain. Metal coatings will not, due to the nature of their structure, withstand sharp impact, squeeze nor edge strain. Where such conditions prevail the fusion of metals obtained by welding is necessary. For instance in the problem presented us by the base-die of dies used for forming dishpans. In this case there was the need to restore the surface contour by building up with metal spray (Fig. 44). This problem was solved by placing a bead weld around the edges subjected to strain (Fig. 45). The basins then formed were fully blast cleaned (Fig. 46) as well as the welded area and built-up with sprayed metal (Fig. 47). The entire area was surface ground without overheating, to the correct contour (Fig. 48).

SUMMARY

Adhering to the general purpose of this paper we have merely attempted to show how the operations are performed successfully. Any one can spray metal, but in itself that is not sufficient. Certain conditions must obtain to assure against the loss of the metal after it is sprayed. It does not matter very much what the character of the object to be sprayed may be. The conditions to which it has been subjected, its present condition and its future use will primarily determine whether or not it is a fitting subject for metal spraying. We must then consider the mechanical practicability of spraying it and unless mechanically ideal conditions like those described in the preceding chapters can be obtained, it is useless to metal spray.

SPOT WELDING OF AIRCRAFT Materials*

By CHARLES L. HIBERT†

INTRODUCTION

A SPOT weld may be described as the joining of two pieces of material by placing them between electrodes under pressure and utilizing the heating effect of a heavy current for a definite period of time. A small slug or spot is fused between the sheets at the point of contact. Spot welds are used to replace rivets, and can be compared to rivets inasmuch as they are designed for shear stress only.

Although Elihu Thompson perfected the process of electric resistance welding in 1886, it has only been the last decade that an attempt has been made to control the various factors and produce uniform and dependable welds. Since the invention of the Electronic Timing Control, the spot welding of aluminum alloys has been made possible. Prior to the development of electronic control, the length of heating was accomplished by manually operated switches. The E. G. Budd Company pioneered with mechanical timing when ushering in stainless steel construction. In the first case, the timing was left to the discretion of the operator—the results were often erratic and the probability of producing welds of the same strength was more or less remote.

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For present size of aircraft, aluminum alloy is the best material that can be used because of light weight and strength. Stainless steel may have the same weight to strength ratio, but the thin gages necessary to accomplish the same weight ship necessitates stiffness and special design to prevent drumming and present an aerodynamic surface. In the full hard condition it is difficult to form. A heat treatable stainless alloy might eliminate more objections to its use, but from a military standpoint it is out of the question because of a lack of supply of chromium in this country in case of an emergency. Stainless alloys are the ideal resistance welding material because of their low-carbon content, high electrical resistance and oxide free surface. If they are ever widely used, it may be safe to predict entire airplanes of spot-welded stainless steel construction.

The Spot Weld Department in an aircraft factory usually consists of one or two machines which are expected to weld the variety of furnishings in an airplane. These are worked out in small units, causing frequent change-overs and a lack of production methods. If the first airplane designed was the one built, perhaps the larger saving could be effected but before the first ship flies several hundred changes are incorporated. Perhaps the automobile industry can remember the same conditions prevailing in the building of automobiles years ago.

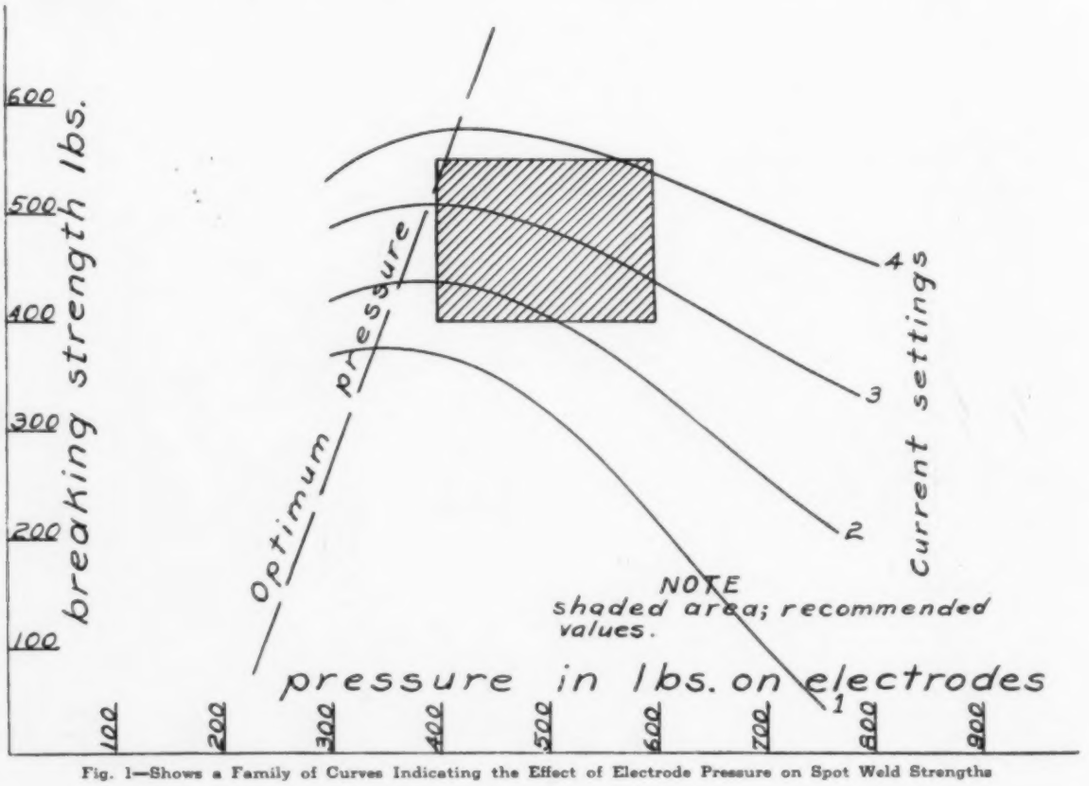


Fig. 1—Shows a Family of Curves Indicating the Effect of Electrode Pressure on Spot Weld Strengths

CONSIDERATIONS

It is necessary to control the variables of current timing, current intensity, pressure on electrodes, diameter and shape of electrodes and sheet condition to produce uniform and dependable welds. One can realize with five variables to control, some of which effect others, it was necessary to fix several arbitrarily until more was known about the process. Fortunately, two separate investigators decided on an electrode tip $^5/_8$ inch diameter $1^1/_2$ inches long with a 7 degree machined tip, and tapered shank to fit a holder and make it interchangeable. Water cooling is accomplished by a $^5/_{16}$-inch hole drilled to about $^1/_2$ inch of the electrode tip. The electrode material must have a better conductivity than the material to be welded, otherwise there will be a loss of energy, due to the greater contact resistance between electrode and sheet than between the contact surfaces of sheet. Although copper alloys appear to be the best material for electrodes, they are not entirely satisfactory for spot-welding aluminum alloys for copper will alloy with aluminum easily causing pickup, exterior splashing, which necessitates redressing of the tips. Chromium offers good possibilities; the conductivity is better than aluminum, it has a much higher melting point and is extremely hard and will not alloy readily. At present, it is not commercially available in a pure form that can be machined. Chrome plating would appear to offer a solution to the problem but somehow or other the conductivity and physical properties of chromium are destroyed in the plating process, either due to included gases or other factors.

Improper care of electrodes causes considerable inconvenience and more unsatisfactory results than any other single factor in spot welding of aluminum alloys, and further progress in the art awaits the development of an improved electrode tip material.

Pressure applied to the electrodes is not as critical as the other variables. It may be varied over a fairly wide range, but when one pressure has been selected it must remain constant for the work in progress. An increase in electrode pressure necessitates a higher current setting because it lowers the contact resistance of the material. A higher pressure will reduce pickup to some extent, but too low a pressure will permit the current to arc between the sheets, causing an explosion and a burnt hole in the work. There has been much quibbling in the aircraft industry as to the correct electrode pressure to use for each gage thickness welded. This is no doubt due to the fact that the current reactance tends to force the electrode arms apart with a force depending on kva. used and the machine design. In some instances this force amounts to 250 lb., which would have to be subtracted from the calibrated pressure to obtain effective pressure on electrodes. It follows a machine with 6-foot arms, and large area between, rated at 400 kva. would require a greater electrode pressure than one with 28-inch arm length, rated at 125 kva. to obtain equal results.

At first it was believed that short periods of current timing was necessary to weld aluminum alloys and prevent the zone of fusion from reaching the surface. Further investigation reveals this is not the case and more uniform results may be obtained by using longer cycles in the neighborhood of ten instead of $^1/_2$ cycles and a maximum of three. The welding of aluminum alloys differs from that of steel; since it has a short plastic range. An actual slug must be cast in the sheet, whereas in steel having a longer plastic range a spot weld is considered a forge weld. This difference accounts for the greater variation, and the inherent weakness in tension or tearing of spot welds in aluminum alloys. The spot weld fails in tension along the boundary of the cast slug and the parent material. In shear the strength is equal to that of a casting in pounds per square inch, for aluminum alloys, whereas in stainless steel, the breaking strength is equal to annealed structure with tension values somewhat equivalent to the shear strength. In welding of steel, current well above 15 cycles appears to give better results which is probably due to working of the weld by the pressure on the electrodes while still plastic. Spot welding of stainless steel requires a controlled time of less than 6 cycles to prevent carbide precipitation and deleterious effect on corrosion resistant properties. Chrome moly and high-carbon steels must be normalized after welding for the welds are brittle, due, no doubt, to the air hardening characteristics of the steel, and the quenching effect of the copper electrodes.

Current intensity required to weld gages of aluminum alloys applicable to aircraft is supposedly in the neighborhood of 5000 to 30,000 amps. Although secondary current cannot be measured directly, it is assumed to be the product of primary current and turn ratio. The effective current available at the electrode is a matter of conjecture because of the variable reactance introduced by changes in set-ups and machine arm positions. An efficiently designed machine may only be rated 70 kva. and accomplished spot welding of as heavy gage as a machine with large cross section between welding arms rated 400 kva. In other words, kva. ratings mean nothing as far as ability to spot weld aluminum alloys.

Any attempt to correlate amperage to be used to weld certain gages of material would be futile. The only procedure is to set the other variables and adjust current values to obtain the optimum weld from shear or tearing tests results. Most parts for aircraft now spot-welded are unstressed, and a weld that will pull a slug with a diameter of four times sheet thickness, in a test sample when rolled apart with a pair of pliers may be considered satisfactory.

The aluminum alloys have a thin naturally acquired oxide coating, which must be removed prior to spot welding. This is accomplished either by mechanical or chemical means. If the oxide coating is allowed to remain on the sheet surface, it increases contact resistance between the sheet and electrode, resulting in serious destruction to the electrode and poor results. Removal of the oxide between the sheets give more uniform welds with less inclusions.

This is also true with steel where the coating is removed by buffing, but in the case of stainless steel, the material is free of oxide and only extraneous material such as paint and oil is removed, no other cleaning being necessary.

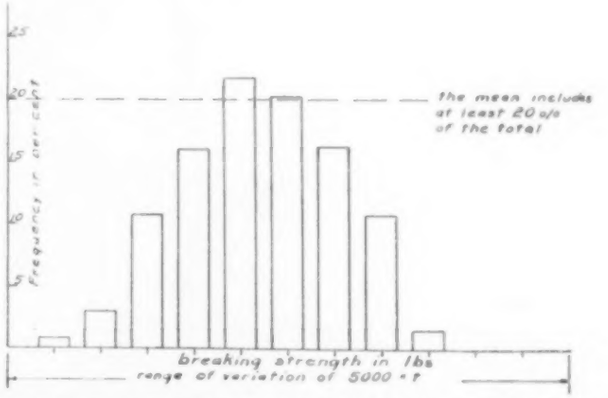


Fig. 2—Shows a Frequency Bar Chart Plotted from the Results Obtained by a Number of Spot Weld Tests. This Chart Shows That a Possible Variation in Breaking Strength Which (5,000 × Sheet Thickness of One Sheet = Lb.) May Be Expected

CLEANING PARTS

For cleaning of aluminum alloys, gum-tragacanth-hydrofluoric acid etching solution, is used, which removes the oxide film and gives a clean surface. The acid, gum and alcohol are kept in separate containers and only mixed in a stainless steel pan prior to their use. The HF acid must be stored in lead-lined containers and storage of any large amount presents quite a problem. The gum is boiled to a molasses consistancy and diluted with water and alcohol when mixed with the acid. The acid is not particularly dangerous in the concentration used but frequent exposure will irritate the skin and rubber gloves are used as a precaution. A lead-lined sink and drain board is provided with running water for washing the acid off after painting or dipping the parts. The cleaning solution is only permitted to remain for a period of about thirty seconds and then the work is put in the running water. It is then necessary to go over the cleaned area with a wet rag to remove the oxide physically. Both surfaces of the joint to be spot-welded are cleaned by this method and remain clean for several days thereafter. If parts are permitted to remain too long after cleaning the oxide reforms with disasterous results, if an attempt is made to spot-weld them. On stock that has been heat treated several times it is necessary to break the film with sandpaper to allow the acid to get beneath the surface and lift the coating free.

The above method of cleaning has reduced labor cost to about one half of that of the obsolete wire brushing method and is less destructive to the alclad alloys. It has also been found best to handle the cleaning of the material, prior to welding, by the spot-welding department, to insure good results and ascertain labor costs.

PRODUCTION

At present there are about sixty-five parts being spot-welded on the present flying boat contract with a total of 13,720 spot welds per ship, which represents a gain of about 50% of the parts previously welded on the same type ship. The trend appears to be on the increase for spot welding of aluminum alloys in aircraft. These welds are effected at the rate of 2000 to 10,000 per shift with about 4000 average per eight hours. I believe 10,000 welds to be the ultimate in speed for spot welding of aluminum alloys, considering polishing the tips with no. 7/10 sandpaper after 6 to 10 welds and a change of tips after every 200 to 400 welds. The day shift consists of two men and the night shift has one operator and two helpers. These two crews handle all of the spot welding, including drills and steel welding.

The largest job in production at present has about 1000 spot welds and the smallest has but three. The jobs are delivered to the spot-weld department, fastened with P.K. screws and disassembled for cleaning. The sequence of reassembling has to be such that it can be all spot-welded on the welding machine as it is impossible to use portable tools as in riveting. With spot welding it is a case of necessity and each job must be planned and assembled in the correct order so that it can be welded between two fixed arms. If it happens that welds are forgotten, in most instances it is impossible to go back and weld them after the next set-up. One may suspect this is a disadvantage; on the contrary, a planned construction is always cheaper. It may be said as yet no job has been refused as inaccessible and spot welders are working where one could not rivet at any price.

Spot welding of aluminum alloys is handicapped by the lack of suitable tips, inexperienced operators, and the lack of a suitable inspection method. Tip material has been mentioned previously, but training of an operator takes considerable time and effort before he becomes dependable. As mentioned in the other articles, an operator who has no previous experience with spot welding is best. Somehow, steel spot welders do not exercise proper care necessary to make good aluminum welders. First, tip condition is critical and to try to explain the necessity to change tips often to a steel spot welder, who perhaps used electrodes day after day, is difficult. They must be polished with care and after evidence of pickup must be redressed. It also takes an experienced eye to place welds in the proper position without any jig or fixtures. With aluminum alloys welds must not be placed too near the edge or in too close to the radii for good fusion. Frequent test pieces must be made during production as a check on the electrodes and character of the welds.

Fig. 3—Is a Nomographic Chart for Spot Strengths. To Obtain the Minimum Allowable Strength per Spot Weld for Any Material, Place a Straight Edge Through the Specification Value for Tensile Strength, Set the Right-Hand Edge at the Desired Sheet Thickness, and Read the Strength from the Left-Hand Column

As exterior appearance of a spot weld means nothing, except in case of bad splashing or appearance of cast structure, a visual method of inspection is out of the question. Therefore, all responsibility falls on the operator to produce good strength welds.

Work must be held at right angles to the electrodes for best results; any skewness distributes the current over a greater area, resulting in a poor weld. The use of one flat electrode is not advisable for the same reason. There are other criteria, that can only be gained by experience, necessary to produce good strength welds in aluminum alloys.

LIMITATIONS

Army and Navy Bureaus restrict the use of spot welding of aluminum alloys to the following materials: Alclad, 52S and 53ST, which can be welded in any combination. Aluminum alloys, other than the above, may be spot welded but are not satisfactory with respect to corrosion resistant properties.

For the Army, cowling, doors, floors and seats may be spot welded without further approval. For other parts, drawings must be submitted for approval of each specific part. Up to the present time, only non-structural parts have been approved by the services. Equipment, personnel and methods must have approval before any spot welding may be accomplished. Spot welding of alumi-

num alloys is still considered to be in the experimental stage and an accurate control is maintained over the application of the process.

The policy of Consolidated has been to proceed slowly and as a precaution finish all long seams with rivets at the ends to prevent tension failures from starting. Parts that are welded are furnishings and of no importance as to strength characteristics.

Although cowling and other parts subject to vibration have been welded I cannot foresee an advancement to stressed parts spot welded of aluminum alloys in the near future, due to limitations of the process and lack of a suitable inspection method.

To set any limits on the size and shape of objects that can be accommodated on spot-welding equipment is hardly possible as special equipment may be designed to reach relatively inaccessible places. It may be said the larger the parts welded the less positive of results. For this reason, spot-welded parts of aluminum alloys should be small and easily accessible, not only from this basis but from a cost standpoint.

Spot welding is cheaper than riveting where the work is open and accessible and where it can be accomplished without frequent changes in tools and set-up. Costs studies indicate a saving in labor costs about $^1/_3$ that of similar riveted construction at Consolidated where riveting is a serious competitor, because most of the work is done with pneumatic tools.

Spot welding of steel is not subjected to the limitations of aluminum alloys. Stainless steel may be considered an ideal material for spot welding, as the welds are strong in tension, shear and torsion. Cost per weld in steel is much less and size of parts has no limitations as portable welding tools may be used. When ships are built large enough to warrant the use of stainless steel we may find row after row of spot-welding equipment. The Alcad alloys are more difficult to spot-weld than the plain alloys because of the difference in melting point of the aluminum coating and the parent material. Pure aluminum has a higher melting point and does not break down as completely as the alloy making an irregular weld, and less consistant results are realized. The aluminum coating lowers the contact resistance necessitating higher current settings to effect a weld, with a corresponding loss of tip life, due to excessive pickup.

52S alloy is the ideal aluminum alloy for spot welding but has low strength and cold working properties.

Several sheets of varying thickness may be spot-welded simultaneously, but in aluminum alloys a wide variation in gage thickness is impractical as the thinner sheet is overheated and there is poor fusion with the thicker sheet. The limit of thin to thick that can be safely welded is in the ratio of 1 to 3. On steel the ratio can be much greater.

Spot-weld shear strength per spot will vary plus or minus 20% from the mean in the alclad alloys and somewhat less for the plain alloys. This spread of strength values will vary with different equipment and methods used to spot weld. This data has been garnered from laboratory samples under ideal conditions and the variation may be actually more in production work.

Shear strengths increase in a direct ratio with increase of sheet thickness. The Army Air Corps has specified a design value equal to $^2/_3$ of the required minimum shearing strength of the single spot test specimens as listed in Table 1. In a joint made from sheets of unequal thickness, the shearing strength is governed by the thinner sheet.

Spacing of welds is specified in increments of not less than $^1/_4$ inch and are usually placed in by eye; therefore, only approximate spacing should be called for. Spacing of spot welds in many cases is similar to that of riveted construction or slightly less. A typical spacing for nonstructural parts is one inch. Another factor for consideration is the loss of current due to the shunting through spots already welded, therefore spacing of spot welds in aluminum alloys, where the effect is greatest, should not be closer than $^1/_2$ inch.

SPOT WELD *VS.* RIVETS

In concluding, I may mention the problem of joining materials. Riveting, as old as craftsmanship, is inefficient from a joint strength stand-point, and costly because of labor and tooling involved. It must be remembered that in order to rivet, a hole must be drilled which reduces the strength of the joint by removal of material. Spot welding does not remove any material and the union is made of the sheet without addition of flux or extraneous stock. To increase the strength of a spot-weld joint, it is only necessary to add more welds while a riveted joint must be redesigned for spacing and rivet size.

On certain metals, notably stainless steel and 52SO material, it is possible to realize a joint virtually as strong as the original material which, from a practical standpoint, is impossible to achieve with rivets.

Spot welds eliminate the projecting heads of rivets, reducing disturbance of airflow on a section. On small airplanes this is quite a factor for consideration as on one particular model rivet heads account for a 30-mile per hour drag. From an aerodynamic standpoint, spot welds present a smooth surface. Spot welding of interior furnishings adds greatly to appearance and is pleasing to the eye. This is a definite value that cannot be measured by cost alone.

Table 1—Spot Welding Data

Thickness Inches	Min. Shear Strength per Spot	Design Strength Shear per Spot	Pressure on Electrodes in Lb.	Time in Cycles
24st Alclad				
0.020	160 lb.	105 lb.	200	3 to 10
0.030	240 "	160 "	300	
0.040	320 "	215 "	400	
0.050	400 "	265 "	500	
0.060	480 "	320 "	600	
52SO Alloy				
0.020	95 lb.	65 lb.	200	3 to 10
0.030	145 "	95 "	300	
0.040	190 "	125 "	400	
0.050	240 "	160 "	500	
0.060	290 "	190 "	600	
Stainless Steel (18–8)				
0.005	140 lb.	90 lb.	100	Less than
0.010	280 "	165 "	125	6
0.015	430 "	285 "	150	
0.020	575 "	380 "	175	
0.025	720 "	475 "	200	
0.030	860 "	570 "	225	
0.035	1000 "	665 "	250	
0.040	1140 "	750 "	275	
0.050	1420 "	940 "	325	
0.060	1710 "	1130 "	375	

NOTES

1. Min. shear per spot is based on the formula $\frac{t \times \text{T.S.}}{7}$ = shear per spot, where t = sheet thickness and T.S. = tensile strength.
2. Design strength is $^2/_3$ of min. shear of single spot values.
3. Pressure may be varied + or −20% from recommended values.

For some materials such as stainless steel, spot welding is the only practical method of joining. Rivet holes are difficult to drill, and the rivets crack under the hammer, due to work hardening.

From a cost standpoint, spot welds cost about one third less than similar riveted construction in aluminum alloys. In steel there isn't any comparison as spot-welding costs drop clear out of sight. Spot welding has been adopted by all of the major automobile industries as a cheap production method. They have achieved unbelievable speeds with specialized equipment, such as spot welding an entire frame of 180 spots in one operation.

I imagine that every infant process is under fire, mostly due to the indifference to new changes and prejudice in favor of the old. Spot welding is not a panacea and to regard it as such is to invite disappointment. But there is something in it and those who doubt its efficiency remind me of the farmer who saw his first giraffe and said, "There hain't no such animal."

Discussion

By WM. A. F. MILLINGER, Consultant
Los Angeles, Calif.

IN DISCUSSING Mr. Hibert's paper, we must not lose sight of the fact that he is utilizing a process whereby the accomplishment of its objective "to join" is dependent upon several factors; pressure of closure, heat by electrical resistance, material characteristics and timing of operation.

Next we must remember that his use of the process is within a specific industry, Aircraft, and that the materials with which he must work are of necessity restricted to those of the aircraft industry and that, therefore, the issues raised and the criticisms directed at spot welding within that industry, does not necessarily apply to other industries.

The aircraft industry did not create spot welding, it adopted it, because of:

1st. Appearance. The smooth surface of interior fittings are not marred as with other methods of joining together.

2nd. Aerodynamics. Other methods of joining the skin surfaces of airplane components together, by reason of their projection above the surfaces, as for instance rivet heads, tend to create a parasitic drag, which affects the performance of the airplane. The use of spot welding, however, where aerodynamic features are involved is permitted only when stress conditions and stress resistance characteristics of the spot weld are favorable.

3rd. Necessity. In the case of materials like the corrosion resistant steels, spot welding is the only practical method to use in the very light gauges adopted.

4th. Cost. Spot welding in connection with specific kinds of materials and in certain classes of work suitable to its use, can show a decided economic advantage over other methods available.

The psychology of aviation is FEAR. Not the "fear of cowardice," but the common sense practical "fear," the discipline and control of which, within the industry from pilot to humble shop apprentice and licensed mechanic, makes for SAFETY. Therefore, we find caution the keynote in adopting spot welding to stressed joints in aircraft. As Mr. Hibert aptly puts it "The Consolidated policy, has been to proceed slowly, and as a precaution, finish all long seams with rivets at the ends, to prevent tension failures from starting. It is that same fear which cautions, "If you cannot inspect it, don't use it," where failure might create a hazard to life and property.

A dampener on the wholehearted adaptation to spot-welded design is that bug-a-boo of the aircraft industry, the limited production of kind in airplane manufacture. Instead of a battery of machines producing a million parts or more, we have one or two machines, changing back and forth, to complete a few hundreds. Such a condition tends to economic stagnation, reduces spread of employment, retards development of processes and kindred industries.

A point often overlooked in the questioning of the use of certain materials in the construction of aircraft, is their strategic significance and availability in the event of blockade by war. We must not overlook this in a survey of the spot-welding facilities of the indicated plant.

The author of this paper has covered his subject in a comprehensive manner, the presentation being undoubtedly for the "knowing" and presuming a prior knowledge of aircraft terminology and electrical background, which is in order as being presented to a group interested in the subject.

Of more than passing interest is the reference to a "lack of experienced operators" and the question arises . . . "Is this due to the newness of the indicated industry and the processes, whereby young men have not had opportunity to apprentice themselves to the trade, or is it because men over the hiring age who have experience (the process having been accomplished in 1886) have not been replaced, or is it due to a geographical isolation from trade centers.

Plan your work, then work your plan is an adage of the production industries prior to the world war, and one from which we can all benefit and still do benefit from. If paper, pencil and eraser were used more and the incidental thought applied first, there would be fewer failures of projects, especially if coupled with the knowledge that comes first with learning, second with discerning and third with experiencing.

Expert knowledge is only a step removed from general knowledge of the subject, sometimes we could wish that the experts would leave us alone for a while and permit us to settle down to one design and produce it. Foreign nations are beating us at our own game, if information that comes to me from engineers over there is correct, and I have no reason to doubt it, engineers are NOT commentators. The public today has forced expert knowledge to stay with general knowledge, hence, advanced modeling has given way to production along less expert lines in the automotive industry and what reflects there, reflects in the aircraft industry more and more as it becomes popular. The aircraft industry could take a lesson from the fact that you cannot educate all the people, all at once to "fly" but you can get plenty of people to fly if you make it cheap enough through production.

We are fortunate that men like Elihu Thompson, to whom we are indebted for the achievement of spot welding by using the phenomena of electrical resistance and current flow of our construction materials, had the ambition, enthusiasm and aggressiveness to overcome mass inertia.

Mr. Hibert has been very frank in his approach and his confidences should be construed constructively, carefully and without haste.

Welded Light-Weight Car Body

THE DEVELOPMENT OF BASIC Principles Governing Car Design and Construction*

By WILLIAM H. MUSSEY†

THE whole country is becoming weight conscious and the Railroads and Allied Industries are alive to the irresistible urge. Much has been done and will be done not only to meet this condition but may be in a relatively few years to change the whole railroad equipment picture.

Stating it bluntly, the saving of a pound of dead weight is of the most vital economic importance.

Pullman-Standard Car Manufacturing Company has confined its efforts to aluminum and low chrome high-tensile alloy steel in the design and construction of its lightweight cars, as a matter of economics.

It is a very interesting thing in considering some of the exaggerated claims of extreme weight savings over present lightweight equipment to realize that for a Pullman sleeper car body framing members only, the weight has been decreased from 58,330 pounds for a conventional riveted car of low carbon normal steel to 26,000 pounds and for a coach to 23,000 pounds both fully welded and it must be evident to all that any further considerable saving cannot be obtained by reducing the car framing with the use of any type of steel of which we have commercial knowledge.

The additional saving must come by taking into account everything that goes inside or outside this car shell, as well as the trucks, and of course we have all been working toward this end, and there is more to be done as it covers a very wide field.

There has been much discussion as to the corrosion resistance of various materials entering into car construction and I think this general term needs some explanation or rather a statement of what corrosion really means.

There are as we see it, two types of corrosion, one is straight atmospheric corrosion which proper maintenance will fully take care of; the other type which is more serious, corrosion due to working of sheets, localization of stresses, etc., which might be called accelerated corrosion which is the problem. Undoubtedly any material which has increased corrosion resistance such as the low chrome high-tensile steel; aluminum except in the presence of alkalies, and stainless steel with its high corrosion resistance properties is a desirable thing but to pay any considerable premium for this quality does not seem to be justified by the facts. The Pullman Company has made various examinations of car structures built more than 25 years ago and others of less age and corrosion present as disclosed by removal of inside finish sheets has been of a negligible character, in other words, we might say it is practically nil. That, of course, applies to passenger cars and result of proper design and maintenance.

Freight cars, of course, come under the same general heading and examination of many of these cars shows that what has been said of passenger cars also applies to freight cars. One very marked example of this is the five welded hopper cars built for the Chicago Great Western Railroad in 1931, as a pioneer development of welded freight cars. The design of these cars was worked out jointly with The Oxweld Railroad Service Company who collaborated with use not only in the design, but in the welding of the cars in the shop. Both gas and arc welding were used in their construction; the amount of the two types of welding being about equally divided.

The coal that is hauled in these cars is of relatively high sulphur content and considerably more corrosive than the average coal; yet from frequent examinations of these welded structures which are of plain open-hearth steel, we have found only a small low rate corrosion and there seems to be no doubt that the life of these cars will not be dependent upon corrosion of the essential parts of the structure. The same, however, cannot be said of riveted cars built at the same time, of the same material and operating under the same conditions.

It is self evident to all that have made even the most casual study of car design and car structures that the only possible way that we may reduce weight in car framing structures is to reduce the cross-sectional area or thickness of the sections, plates, bars and sheets that go to make up this structure and thereby take full advantage of the physical characteristics of the steels.

A study of welded construction convinced us that a welded structure properly designed and built would produce the strongest and lightest car, and welding with us

* Extracts from an address presented on January 11th before the New England Railroad Club.

† Engineer of Research, Pullman-Standard Car Manufacturing Company.

is used as a means to produce the result—the light-weight car.

It was further decided that the light sheets and in fact practically all of the superstructure would have to be spot welded, both from a design and commercial standpoint. Arc or gas welding has the greater value in fabricating the underframe members, and should be used, therefore, for the best results.

In 1935 we built a light-weight box car of Cor-Ten Steel in which the underframe was partly arc welded and partly riveted. The superstructure was spot welded. This car was built as an experimental light-weight car for the purpose of determining suitability of low chrome high tensile steel, or the soundness of the principles of design, the practicability of the type of welding equipment employed and the possibility of building such a car weighing $4^1/_2$ tons less than, but at the same cost as the A. A. R. standard car.

The box car was tested by the A. A. R. for static and live-load vertical loadings and under impact tests and after that put in service and has made in excess of 26,000 miles with no repairs and has given good service.

Shortly after this we built an alloy steel welded refrigerator car with outside welded steel sheathing. The underframe was fully arc welded and the superstructure spot welded, using the same equipment for spot welding as had been used in connection with the box car.

The refrigerator car represents a saving of 10,000 to 13,000 pounds in light weight over other cars of similar size and that car has made approximately 40,000 miles with only slight repairs other than the usual run of maintenance items such as brake shoes, bearings, etc.

This demonstrated to us that a welded car could be built for severe service and it would give good results and be perfectly satisfactory.

Under the impact test of the light-weight box car (PLM 500) we had a chance to study a combination of riveting and welding on the underframe, the practicability of the spot-welding equipment available at the time this car was built and to study methods for reducing costs.

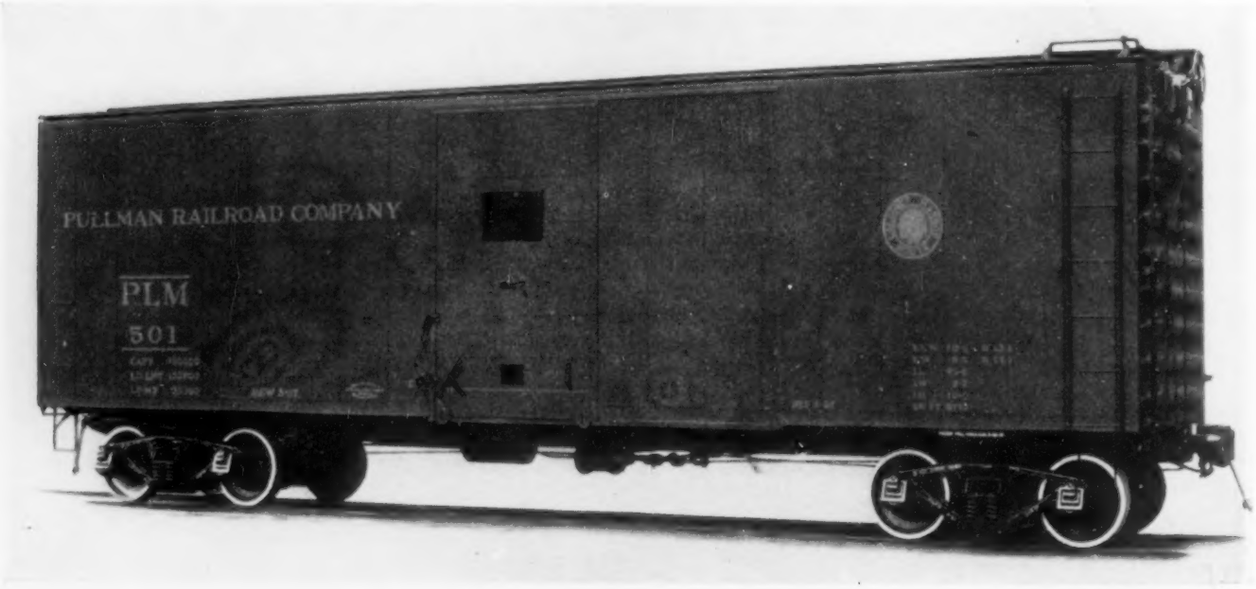
After a very careful analysis of the results obtained from impact testing and of the car in service, we thoroughly explored the field of spot-welding technique and equipment. In the first part of this year we convinced ourselves that steel freight cars could be produced at a low cost with absolutely reliable welds. The previous designs needed some modification to use the best that there was in spot welding. The same general fundamentals could be followed as practiced on the first car. The combination of riveting and arc welding on the underframe was not the equivalent of a fully welded construction. The center filler, back stop and the striking members were built up of rolled plates welded into the center sill conforming to the construction we have applied to many cars with most satisfactory results.

In April of this year we were authorized to build another welded box car, of the new A. A. R. dimensions which are larger than the previous standard. The car was completed in May and was on exhibition at the A. A. R. Convention at Atlantic City in June. It represented a saving of approximately 5 tons in dead weight over the A. A. R. box car of similar large dimensions.

In all of these cars we have used light-weight chilled iron wheels which have represented a reduction in weight of 680 pounds per car and frequent inspection of these cars has demonstrated their serviceability.

This car has been subjected to most severe static and live load vertical loading and high speed impact tests. The A. A. R. representatives and many railroad men were present and witnessed these tests. None of the members of the car structure were distorted. Of the approximately 14,000 spot welds in the superstructure not one of them let go. In other words we have proved that welded light-weight structures as represented by this car will assure the railroads of the ultimate in light-weight and strength, that the cars will not be on the repair track but in service and the study of construction methods has convinced our company and they have stated publicly, "This car can be produced without any premium in cost over the conventional riveted car."

As a further step in connection with the statement above, one of our freight car building plants is providing facilities and equipment which has been ordered and will be installed for producing approximately 25 cars a day of this light-weight welded construction. The plans are to have this plant in operation within a month. The welding equipment will be largely automatic and the handling



Welded Light-Weight Box Car

and fabrication will eliminate as far as possible manual handling.

It might be of interest to give more information about the methods followed in making the tests. As we mentioned previously, after the light-weight welded box car was built, it was thoroughly tested. In this series of tests we applied at approximately 125 positions on the car body instruments which would record the stresses under both static and live load conditions but, of course, the static conditions mean very little as compared with those of live load or impact.

MR. BUTLER—What is the maximum thickness of metal that you can successfully spot weld?

MR. MUSSEY—We have successfully spot-welded quarter-inch alloy steel. That would mean close to $^3/_8$ inch in open-hearth steel. I may be $^1/_{64}$th of an inch off on that. We have not spot-welded any $^3/_8$ inch, but we have done quite a little quarter inch spot welding. The difficulty is in getting the sheets together without playing havoc with the electrodes.

About welding, we too have thought it was desirable to reinforce certain members. You probably noticed at the bolster and at the door there were certain buckles on the side, at the side sill. We took this car and ran some preliminary tests before we gave it the final test, and we found that to iron out certain stresses it was desirable to reinforce certain members, a negligible addition, as far as weight was concerned. We arc-welded there reinforcements.

It might be interesting to know that the type of cushioning device has a very practical effect. If you take the impact stresses before you get to the bolster you get the full force at the end of the car. We have had some cases where that reading went up as high as 45,000 pounds per square inch. In other cases the reading was 7500 pounds per square inch.

MR. MCMUNN—The car Mr. Mussey has designed, I believe, has steel sheets welded in position and it would be interesting to learn, in the event one of the sheets, requires renewal, just how he would go about doing it. Undoubtedly, this has been carefully thought out by him, but it being such a vital matter in the maintenance of refrigerator cars, it is a subject, it seems to me, worthy of the most careful consideration by those engaged in the design of such equipment. I would be glad if Mr. Mussey will enlighten us about this.

MR. MUSSEY—In the first place, we have taken due account of that, or we think we have.

You will notice that we put these members in rather small sections, so that you have always some supporting member to go to.

With that construction that we have there I would say that it would be possible to put in a partial sheet or a whole sheet just as easily or easier than you put in a riveted sheet. That has been our thought. You have to get in there to drive rivets. If you want to put them on by means of any of these various methods that are commonly used, you can put them on with a "Huck" rivet, such as we use in aluminum cars. You put a plate on there and it is "Huck" riveted and it will hold as well as any other rivet.

WELDING THE NEW LIGHT-WEIGHT Pullman*

By A. M. UNGER†

THE old conventional cars were satisfactory for riveting. The sections of the sheets, plates and structural members used were large enough so that when rivet holes were punched in them the net areas were sufficient to carry the required load. Bearing areas for the rivets were ample. In order to reduce the weight of the new cars, it was necessary to go to lighter sections, using the newly developed low-alloy high-tensile steels. With these thinner members, the bearing areas for rivets and the net area for load stresses was no longer sufficient. Because of the thinner sections, and the need for waterproofing, rivets had to be spaced closer together. This meant that the sections were still further reduced. Rivets were smaller and no longer capable of carrying concentrated stresses. Therefore, after a thorough analysis of these conditions it was found that in order to make the light-weight car it was necessary to weld it. The side, ends and roofs of the car, having light gage sheets are spot welded, while the underframe with slightly heavier sections is arc welded.

Underframe

The backbone of the underframe is the center sill. The center sill of the light-weight car is formed by welding two Z sections together to form a flanged U section, the standard A. A. R.† center sill. The center sill is automatically welded from end to end by a newly developed process in which a flux is spread over the joint ahead of the electrode. This flux serves two purposes, first to protect the weld from atmospheric contamination and second to take an important part in the development of heat, for making of the weld, by the passage of the electric current through the molten flux. The weld produced is very uniform in appearance and quality.

The various cross members of the underframe such as bolsters, crossbearers, end sills and buffer wings are welded together manually with the electric arc. Each member is built in a jig and carefully gaged so that they will fit when assembled in the underframe.

The underframe assembly takes place in a jig into which the center sill is first placed. Then come the bolsters, crossbearers, floor stringers, etc. in their proper positions. After being fitted, and gaged by the Inspectors, the underframe is welded into one rigid assembly.

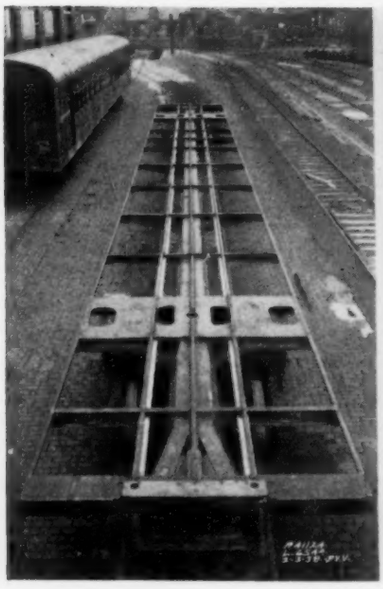
Sides

The side sheets of the light-weight car are assembled by spot welding. This is done on a special jig and by means of a special series spot-welding machine. This jig is faced with copper bars that back up the framing

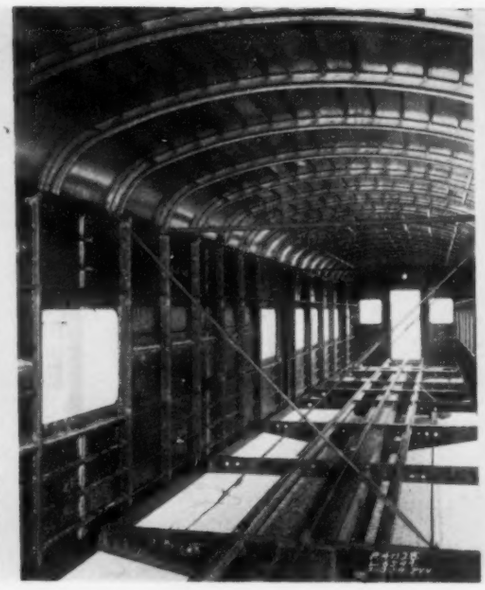
*Presented before Chicago Section, AMERICAN WELDING SOCIETY, Dec. 17, 1938.

†Welding Engineer, Pullman-Standard Car Mfg. Company, Chicago, Illinois.

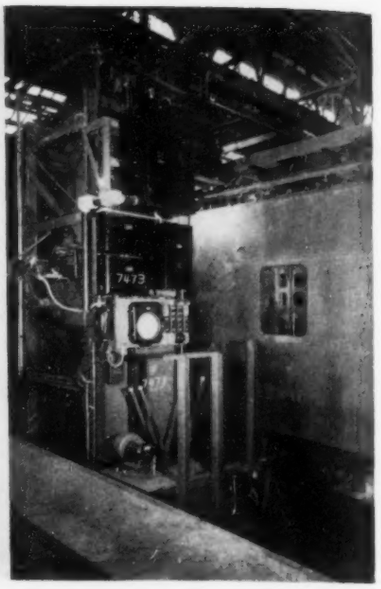
†Association of American Railroads.



Arc-Welded Underframe



Interior View of Car During Construction



Exterior View of Car During Construction

members to which the side sheets are spot welded. The spot-welding machine has two electrodes which are applied to the outside face of the side sheet. The copper backup resists the pressure of the electrodes and conducts the current on the reverse side of the work from one electrode to the other, thereby producing two welds in one operation.

The car sides are of the flat girder type and are assembled in the vertical position of the jigs, which are the full length of the side. The framing members are assembled on the jig first and firmly clamped into position. Arc welders join the connections between the framing members. The arc welds are ground flush so that when the side sheets are assembled in position, they will fit the framing without any interfering projections. Before the side sheets are assembled on the jig, stiffeners are spot-welded to them in sub-assembly. These side sheets are held in position on the frame work of the side by means of self-tapping screws. This leaves the surface free of clamps that would interfere with the spot-welding operation. When the side has been spot welded, the screws are removed and the hole filled by arc welding.

The side spot-welding machine is rated at 200 kva. and is capable of welding vertical or horizontal rows of spots on the car side. It automatically spaces itself. The operator merely starts the machine, stands by, watches it weld, and stops it when the end of the row is reached. The electrodes automatically move out to the work, make two welds and then index over to the next position and repeat the operation.

Electric-power to the welding transformer is delivered to the carriage by means of trolley shoes connecting to two trolley wires. Two shoes in parallel on each wire are used to insure good contact.

The control used to time the welding current is of the electronic type operating a contactor. The feature of this electronic timer is its ability to energize the magnetic contactor at the same point every time in the A.C. voltage wave. This keeps the timing very accurate. Adjustment of the welding time is by means of a dial switch in the control cabinet.

In order to line the machine in the proper position to weld the side sheets to the posts, which cannot be seen by the operator as they are covered by the side sheets, the operator moves the machine until a signal on the operating panel operates. This indicates that he is in the proper position to weld.

Horizontal rows are located by means of an indicator on a vertical rod. The operator moves the unit up or down so as to locate the indicator on a marker on the rod.

To reduce distortion of the side sheets by the welding heat, the electrodes are surrounded by a water spray. This spray keeps the sheet cool ahead of the electrodes and prevents it being welded in an expanded condition. When the car body exterior is painted the welding spots are completely hidden, and the whole side presents a smooth flush surface.

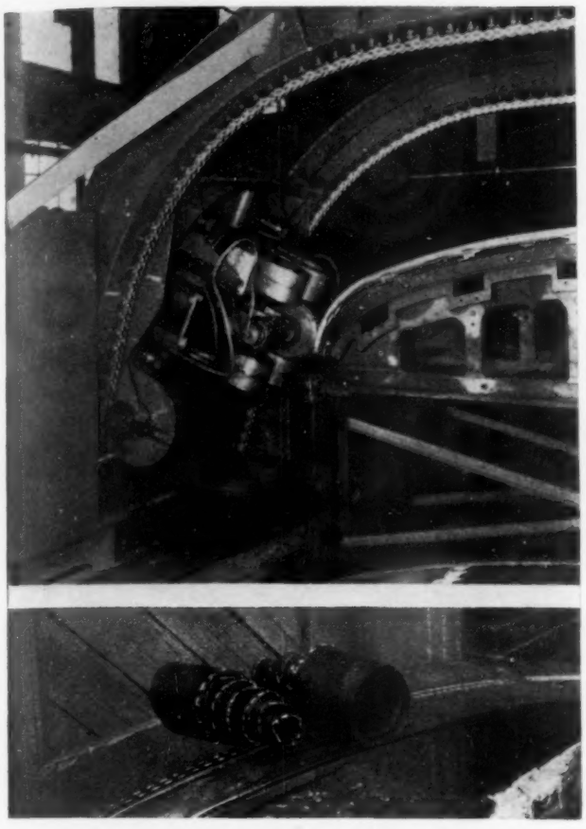
Roofs

The roofs for the light-weight car are spot welded on a special jig built full length of the car. The cross supports of the roof, called carlines, are clamped firmly to copper faced supports which have the same shape as the carline. Roof sheets butt together on these carlines and are spot welded to the carline.

The roof sheets are firmly held on the jig by means of steel straps held at each side of the roof by eccentric clamps. The roof sheet is supported on the underneath side by wooden supports placed directly beneath the straps. There are four of those straps on each roof sheet. They serve to hold the sheet while it is being spot welded, so that it cannot move and become distorted.

Each roof sheet is reinforced by Z-bar stiffeners that are spot welded to the sheets in sub-assembly. The roof spot-welding machines also operate on the series principle. Rolls similar to those on resistance seam-welding machines are used. The two rolls run side by side about one inch apart. They straddle the butt joint of the roof sheets on the carline. The welding current goes through the sheet and carline from the electrode to the copper back up and up through the carline and sheet to the other electrode roll, thereby making two welds at one time. In order to insure that there will be no current shunted from one sheet to the other, a string is placed in the joint separating the two sheets. The welding current is controlled by an electronic timer so that as the rolls move along the joint always remaining in contact with the sheets, the current is regularly interrupted, thereby

Close-Up Roof Spot-Welding Machine



Test Sample Made on Roof Spot-Welding Machine

forming spot welds uniformly spaced along the joint. The pressure of the rolls against the sheets is kept constant regardless of the position of the rolls from the top of the roof to the side.

The welding transformer with the electrode rolls assembly is mounted as a unit on a carriage. This carriage in turn is supported by two curved I-beams that have the same contour as the roof. The welding unit or "head" is moved along these beams by means of a motor and sprocket wheel which engages with a chain rack mounted on the beams. This entire assembly moves longitudinally along the roof on tracks parallel to the roof jig.

The timing of the welding current is by means of a complete electronic control. This is the most accurate method of controlling welding time of spot welders known. Not only does it give the exact number of cycles required time after time, but the transformer is always energized at the proper point in the voltage wave and the current is always interrupted when it is at the zero point of the A.C. wave. The spacing of the welds is adjusted by means of this control. The length of time that the current is off determines the space between the welds, as the rollers moving along the roof at a constant rate of speed.

Checking of Spot Welds

After the sides have been spot welded, they are carefully checked by means of a rubber hammer for loose spot welds. The rubber hammer, which has been found to be a very useful instrument for spot-weld inspection, consists of a light-weight ball-peen hammer with a standard rubber cap, such as those fitted on chair legs, fitted over the head of the hammer. A light blow is struck right over the spot weld. If the weld is loose a distinct click will be heard. After a little practice the Inspector becomes very efficient in the use of this hammer. In case of doubt a pry-bar is used inside of the car. Any loose spot welds found are repaired by means of plug welding.

Assembly of Sides, Ends, Roof and Underframe

The assembly of the sides, ends, roof and underframe is done by a combination of riveting and arc welding.

HOW THE WELD IS MADE

The process of spot welding consists of passing a current of several thousand amperes at a low voltage through two or more pieces of metal, while applying mechanical pressure at the same time. The pressure is applied by the same copper alloy electrodes that conduct the current to the work. The enormous current rapidly heats the metal between the electrodes to a welding temperature. The pressure applied forces the plastic metal together. The weld cools as soon as the current is turned off and the pressure is then released.

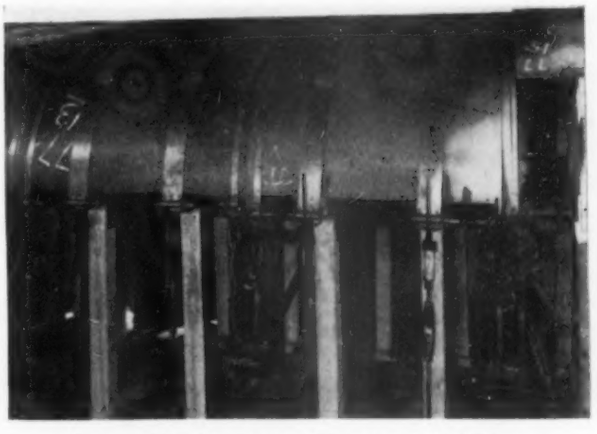
With the "Series" process used on the welding machines being described, two electrodes contact the work on the same side. The welding current travels from one of the electrodes through the work to the copper face of the jig, through the jig, to the other electrode. Thus, two welds are made at the same time.

MAKING SETTINGS ON MACHINE

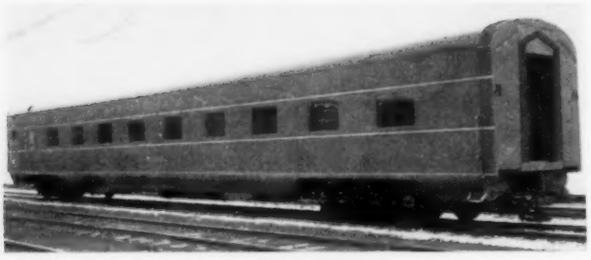
To determine the settings to be used in spot welding of car sides or roofs the following factors must be taken into consideration:

1. Kind of material
2. Thickness of material
3. Size of spot desired
4. Spacing of welds desired
5. Metallurgical effects upon weld-metal
6. Buckling of panels
7. Area of material in magnetic field of welding current
8. Variations in fabrication
9. Variations in surface conditions of sheets being welded
10. Maintenance of electrodes
11. Appearance of welds

A setting must be chosen that gives the best possible results when all the factors are considered. The four



Section of Roof Jig Showing Clamping of Roof Sheets



Completed Car

settings to be determined are: (1) welding current, (2) welding time, (3) welding pressure and (4) size of electrodes.

To actually determine the best setting that will satisfy all of the conditions enumerated above, samples are made and tested for a wide range of settings. Current is varied from minimum to maximum for various settings of time, pressure and electrode size. Tests are made to determine strength of welds, hardness of welds and buckling of panels. The strength tests consists of tensile, shear, shock and fatigue tests. After all the results of these tests are reviewed a setting is chosen that will best satisfy all conditions.

The final samples that are made and tested, are full size sections of the car roof and side. After examination for appearance, these samples are torn apart to check machine settings.

The settings chosen are made so as to take care of commercial variations that occur in fabrication and manufacture of material.

KEEPING SETTINGS CONSTANT

After the machine settings are made they are kept constant. The current is kept constant by keeping the line voltage constant. A special line for these welders is run direct to the power house to avoid any fluctuations due to other equipment on the line. At the power house automatic regulators keep the line voltage constant.

Air pressure is kept constant by means of an air regulator. The pressure that is used is below the regular line pressure, so that line variations will have no effect on the welding pressure.

The welding time is kept constant by means of electronic controls. These controls always measure out the same length of welding time.

The size of the electrodes is kept constant by using the best possible alloy of copper available for this purpose, and frequent renewal.

HOW SETTINGS ARE CHECKED

In order that a positive knowledge may be had that all machine settings are remaining constant special instruments are provided.

A voltage meter is provided for checking the line voltage to the welding machine at any time. This insures that the welding current is remaining constant.

An air pressure gage is provided so that the operator can at any time check the welding pressure.

The welding electrodes are checked for size, by means of a templet, before being used, and are changed frequently so that "mushrooming" will not change the size of the electrode. Only machined electrodes are used. The operator is not permitted to dress an electrode with a file.

FREQUENCY OF CHECKING SETTINGS

All settings are checked every morning before starting to work. The operator keeps his eye on the gages and meters he is provided with throughout the day. Checks of timing are made at any time desired during the day.

Between every roof that is welded an actual carline is welded to two full length strips of the same gage as the roof sheet. The sheets are torn from the carline and the welds inspected by an Inspector before proceeding with the next roof.

Savings in Weight

The weight of the shell or framework of the Pullman car has been reduced over one-half of the original weight. The complete new car weighs two-thirds as much as the old car. This has been made possible by the use of alloy steel and welding.

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MODERN TRANSPORTATION

Welding Extensively Utilized in Articulated Rail Car Fabrication

By GEORGE SYKES*

RECENTLY completed light-weight, streamlined, articulated, two-car rail units constructed by a prominent manufacturer of railway cars mark further advance in the use of alloy steel and welding in the railway field. These new units, offering improved travel facilities, were designed to make possible their use with car units of present standard type; or by starting with this new unit as a foundation, the building of an entire train of light-weight units is practical.

The extensive use of alloys, both steel and non-ferrous, in the body construction and in the interior furniture and finish, give the two-car unit about the same weight as one standard car. Unique in their design is the incorporation of two floor levels to make a "duplex" arrangement.

Experiments going back to 1932 convinced the car manufacturer that the "duplex" arrangement and the use of welded alloys were not only practical but also of sufficient economic value to make it worth while to enlarge on the idea and build more cars of this type.

One car of the first new unit built contains 16 rooms. Of these, 14 are equally divided between single rooms on the floor level and others reached by three steps. The transverse bedroom, with a daytime sofa that converts into a bed, is featured. Individual toilet facilities and individual room air-conditioning control are innovations.

Many facilities designed to make travel more comfortable are incorporated. A folding aluminum table may be used for writing, the serving of meals, or recreation purposes. There are arm rests that fold into the back of the sofa. Compartments to hold magazines, eye glasses and a watch or clock are handily located.

Six of the downstairs "duplex" rooms may be enlarged by removing a sliding partition. Thus, two rooms may be made into one large room.

The second car of the first unit contains a compartment and three double bedrooms. A buffet equipped with a broiler, coffee urn and refrigeration facilities is placed at the head of the observation lounge. The lounge occupies practically half the length of the car. Tubular aluminum welded furniture of modern style

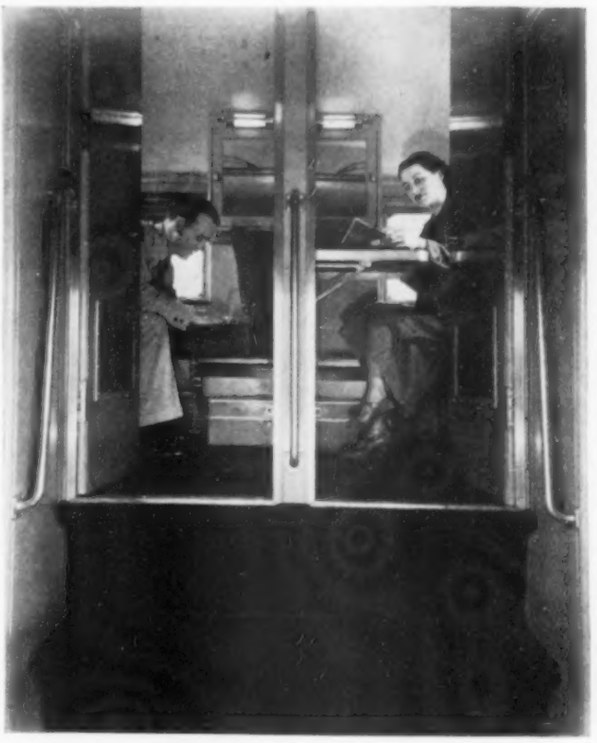

Fig. 1—Welded Alloy Steel for the Car and Welded Aluminum in the Interior Finish and Furniture Make This New Two-Car Rail Unit with "Duplex" Rooms Unique

* The Linde Air Products Co.

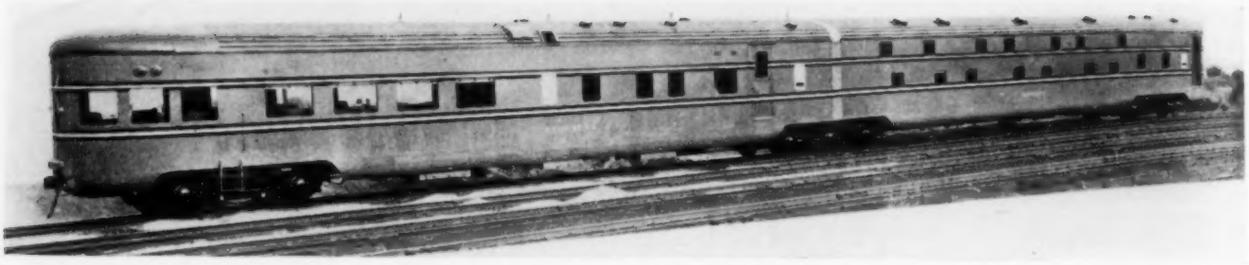

Fig. 2—Over 1000 Ft. of Oxyacetylene Welded Aluminum Went Into the Cabinet Assembly of Two "Duplex" Streamlined Units

Fig. 3—Modern, Distinctive Aluminum Furniture in the New Cars Was Made Practical by Use of the Blowpipe

completely fabricated by oxyacetylene welding gives comfort and eye pleasure to the travelers.

The spacious observation end of the car is in two sections. An observation parlor seating six is at the rounded end of the car. The lounge seats twenty and has sofas and section seats with tables.

Practical features of the construction of the car and interior furniture are of interest. In the first unit about 2098 feet of welding was carried out on alloy steel in the fabrication of the car parts such as the center sill, body bolster, turn plank, door parts and similar parts. The second unit has 1810 feet of welding.

In the interior on the standard cabinet assembly and trim, about 100 feet of steel and over 500 feet of aluminum was oxyacetylene welded. In the second car, 500 feet of aluminum and over 100 feet of steel was assembled similarly.

All of the aluminum furniture was fabricated by means of the blowpipe in both units. The silky satin finish and absence of all evidence of joints were made possible by this method of assembly.

WELDED BIN—DESIGN AND DETAILS

By MARTIN P. KORN*

IN AN all-welded bin recently completed, several new features employed made for distinct savings in cost and time. The bin, 14 feet square by 10 feet deep was prefabricated in two units, upper and lower. The upper unit telescoped into the lower one in the field. Their exact matching was not required because of field adjustment features around which the design was planned. Those adjustments were practically automatic. That eliminated exact shop work and kept the fabricating costs down. It also made for the easiest and quickest erection despite size variations in both units due to welding distortions. The columns were swung into place, the lower prefabricated unit followed, then the upper unit, and the structure was ready for the field welding. The procedure followed is illustrated in the erection diagram.

This welded bin was designed for a plant manufacturing concrete pipe. The following conditions had to be met: Its supports were to be independent of the building columns, a minimum of 12 ft. trucking clearance under bin was required on four sides, the bin was to have four divisions for varying grades of sand and broken stone, it was to be "home-made" by their one and only welder. All requirements appeared simple except the unknown equation in the last one. Since the success of the welded bin and the installation of additional ones depended upon that welder's qualifications without fabrication or erection experience, utmost simplicity in the design was my first consideration. That was in no way to conflict with the necessity for economy. The finished structure successfully fulfilled all requirements. Its high-lights will be briefly reviewed.

Making the bin square and placing the columns radially (at 45 degrees) made for the following:

(1) All four columns exactly alike,
(2) All outside plates, bottom (sloping) plates and stiffeners exactly alike and interchangeable on four sides except the partition plates.

No corner connection angles were used, no bent plates were used—as for riveted bins and some welded bins.

Figure 1 is a top view of the upper prefabricated unit, Fig. 2 a cross section. An end view appears in the erection diagram. This unit includes the outside plates 6 feet deep, the partition plates 10 feet deep and 4 stub columns 5 feet in length. The lower portions of the outside plates extending 1 foot below stub columns were field welded to main columns below. That strengthened the column splices and made the upper unit work toward bracing the columns. The outside plates were welded continuously to inside flanges of stub columns and intermittently to their webs. Three horizontal channel

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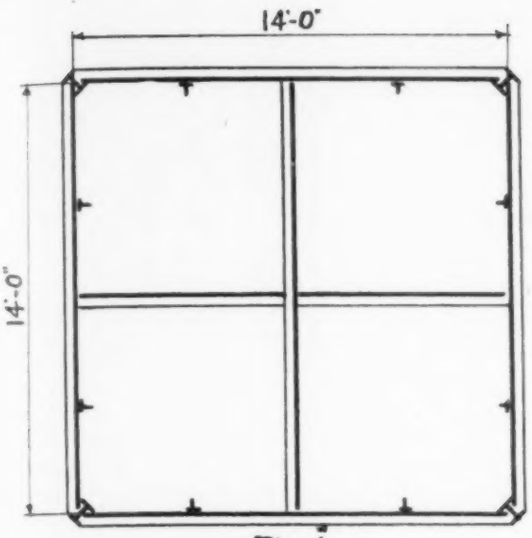


Fig. 1
Top View-Upper Unit

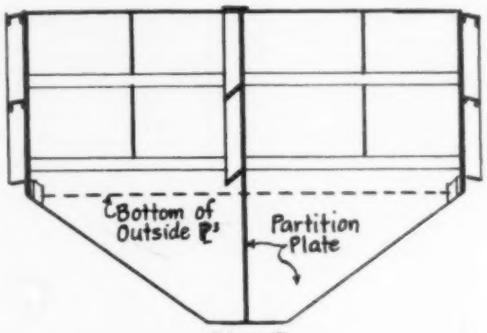


Fig. 2
Cross Section-Upper Unit

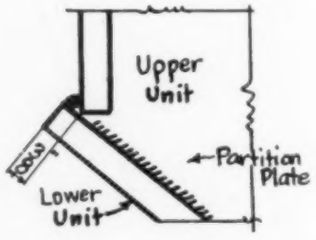


Fig. 3

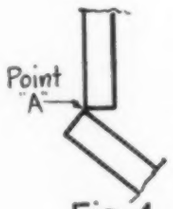
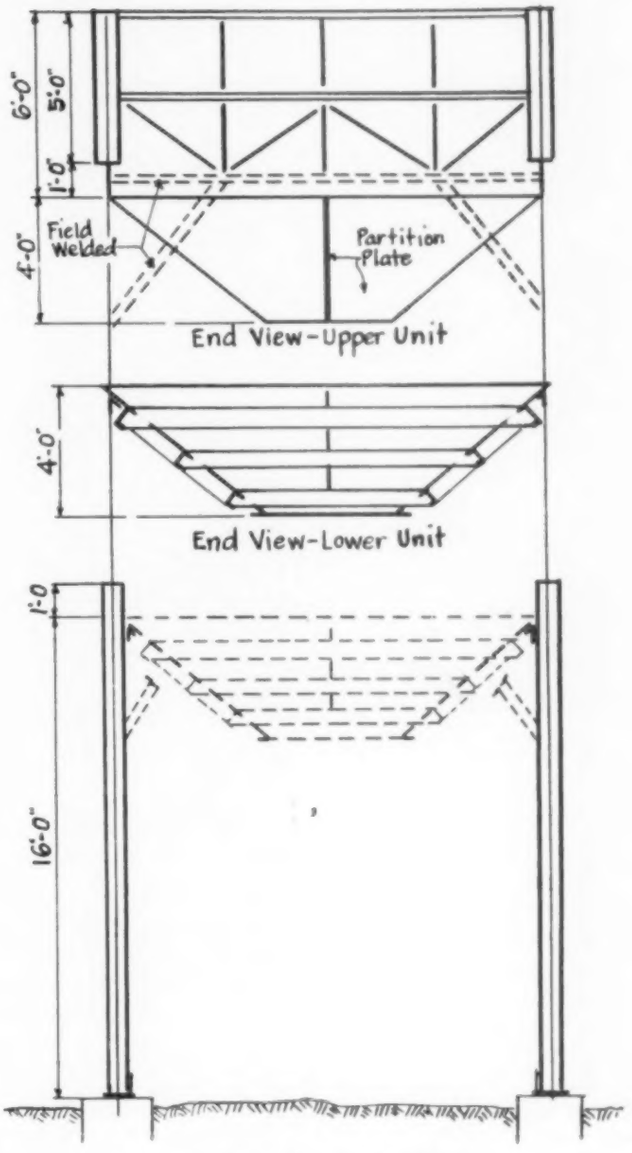


Fig. 4



Erection Diagram

stiffeners spanned the full width of bin and were welded at ends to the columns. The lowest one was omitted until after lower unit was field welded. Column splice plates were shop welded to stub columns.

The partition plates in the upper unit are shown in Fig. 2. One spanned full width of bin 14 feet, functioning as a girder supporting lower unit (that will be further explained). Plates were used as web stiffeners on only one side of web to a depth of 5 feet 6 inches below top of bin. The horizontal stiffeners were sloped to permit flow of material.

Referring to the erection diagram, the lower prefabricated unit was bolted to columns (lightly) through clip angles shop welded on underside of this unit. The upper prefabricated unit was then lowered. Its projecting splice plates (not shown in sketch) guided the unit into position over the supporting columns as the stub columns settled to full bearing.

Figure 3 illustrates the manner in which the upper unit telescoped into the lower one. The lower unit was field welded to the upper one continuously around its perimeter and along the partition plates. Continuous welding was not required for strength. It was employed for wearing and sealing purposes. To provide against extreme variations in distortions of both units likely to cause a condition as shown at point "A" in Fig. 4, eight tees 6 inches long were shop welded to upper unit and field-welded to lower unit. They are shown in top view of upper unit and in its cross section. Those tees would in themselves sustain the lower unit with full live load. Their slight cost insured an absolutely safe structure. However, this "worst possible"

condition did not develop because of simple and concise shop welding instructions that accompanied the design. The welder followed them without head-scratching and with excellent results. Both units were fabricated mostly upside down eliminating overhead welding. In the lower unit the valley joints were butt welded and the channel stiffeners on outside were welded to each other at their ends.

After the lower and upper units were welded, two knee braces (light H beams) were welded at each column to bin. They are outlined in end view of upper unit. In conjunction with web stiffeners (on outside only) consisting of vertical and inclined plates forming a truss with the two horizontal channel stiffeners, the structure was rigidly braced. (X bracing was prohibited on account of required trucking headroom). The inclined plate stiffeners were back 1 inch at bottom and 2 inches at top. Accuracy was thus not required for their fabrication and their cost was small.

The column bases designed as fixed ends had welded "boots." A plate for support of four bin gates was shop welded to lower unit and field welded to partition plates of upper unit. No pieces were milled except the columns. The field welding was confined mostly to joining of lower and upper units. All welding was by the shielded arc process. The bin was sealed within throughout. Continuous welds were used only for sealing. All other joints had intermittent welds mostly $^5/_{16}$ inch.

Comparing the above design with other types: A welded bin of the conventional riveted design having connection angles and bent plates would have required at least 1220 lb. of additional steel and at least one-third more welding and weld material. A riveted bin would have required at least 1220 lb. of additional steel, the punching of 1552 holes, a minimum of 976 rivets. Experience in the design of all types points to distinct savings in the employment of welding. However to profit most from welding's full advantages, conventional riveted designs should be avoided. Welding demands simplicity, a reduction in number of assembled pieces, a minimum of joints, a minimum of field work.

A MONEY-SAVING APPLICATION

Use of an Oxyacetylene Cutting Machine Effects Two Direct Savings at Once

By E. R. MECLEARY*

A COMPANY which manufactures concrete mixers recently purchased a portable oxyacetylene cutting machine and was able immediately to realize two direct savings in cost.

The particular type of mixer made by this company involves the assembly of three prefabricated units, each of which is made of steel plate. The center unit, forming the body of the mixer, is a cylindrical steel section made by rolling a plate to the desired diameter and then welding the longitudinal seam. Two dish-shaped head units are welded to the open ends of this cylindrical unit to form the tank in which the concrete is mixed. Each of these head units has a circular opening, to permit putting dry materials into the mixer at one end and dumping the mixed concrete at the other.

THE FIRST SAVING

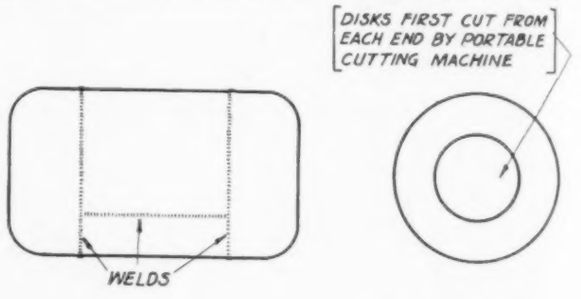
Before the purchase of the portable cutting machine, this company bought these head units from another manufacturer with the openings already cut. Now, however, the company buys the head units without the openings, and uses its new cutting machine to make the openings. In addition to this saving in cost, they now have the circular disks of steel available for their own use. Heretofore, although they paid for the weight of the steel, they did not receive the cut out disks.

THE SECOND SAVING

The rotating drive mechanism for one type of mixer made by this company is located at the end of the shell. To attach the gear for the drive mechanism, a hub is first secured to the end of the shell and the drive gear then welded to this hub.

The drive gear is composed of a gear ring with a steel

Fig. 1—The Standard Mixer Shell Has Had Openings Cut in Both Ends



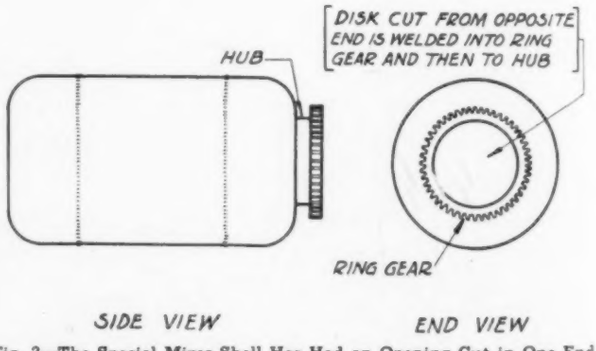


Fig. 2—The Special Mixer Shell Has Had an Opening Cut in One End Only

disk welded into it, the disk being the same thickness as the mixer shell plate. It was found that the disks cut from the head units by the new cutting machine were the same diameter as those carried in stock, thereby making it possible to eliminate completely an expensive inventory item.

* The Linde Air Products Co.

PROBLEMS CONNECTED WITH THE Development of a Standard Code for Large Welded Steel Pipe for Hydraulic Purposes*

By Dr. W. F. DURAND†

THESE are days of Codes, of Standards and of Standardized Practices, and I need spend but little time in discussing the function of a code as such. However, with reference to the special code under present notice, certain general statements may be made.

First with regard to the field of design and fabrication which this code is intended to cover.

There are already the standard A. S. M. E. and A. P. I.-A. S. M. E. codes for unfired pressure vessels, in which the problems of design and of fabrication are very similar to those for large welded steel pipe for hydraulic purposes. There is also a code under formulation for smaller pipe in what may be called commercial sizes.

It might be questioned, then, whether with these two codes, there is need for anything further.

Experience seems to indicate, however, that there are a number of problems measurably peculiar to the design and fabrication of large welded steel pipe for hydraulic purposes—problems and conditions not adequately covered by the codes now in vogue, and justifying the development of a code specially adapted to this important field of engineering practice.

GROUND TO BE COVERED BY THE CODE

The content of such a standard code for the design and fabrication of large welded steel pipe should include the following principal items.

1. Grades or specifications of sheet steel which may be employed.
2. Specifications of such other materials—cast steel, structural steel or cast iron, which may be employed, with the conditions and limitations of such use.
3. Specifications for any auxiliary materials such as bolts, studs, nuts or other like items of standard engineering production.
4. Description of the types and forms of welded joints which may be employed, with the conditions and limitations of such employment.
5. Rules for the design of the thickness of the shell of the pipe as conditioned by the following:
   - (*a*) The maximum pressures to which the pipe may be subjected.
   - (*b*) The grade and quality of steel employed.
   - (*c*) The technical processes to which the pipe is to be subjected after welding of the joints, and including allowance for examination by X-ray, magna-flux testing and stress relieving.
   - (*d*) Allowance for corrosion or excessive wear where such conditions may assume a rôle of importance.
6. Rules for the design of pipe specials and fittings such as elbows, T's, Y's, stiffening rings, supports and their attachments, reinforcements around openings closed by manholes, etc.
7. Rules for the testing of welders and of welding technique.
8. General rules and requirements covering the principal operations in the technique of fabrication.
9. General rules and requirements covering the subjects of inspection and tests.
10. Rules for the routine testing of welds during the process of fabrication.
11. Rules for such special technique as may be called for in connection with the assembling and erection of a pipe line in the field, as distinguished from the technique of fabrication in the shop.
12. Rules for the special operations of stress relieving, radiographing and testing by magna-flux.
13. Rules for the testing by hydraulic pressure of pipe sections or specials, or of a pipe line as a whole after erection in the field.

OBJECTIVES TO BE REALIZED

With a code of this general content, accepted by the industry and by the purchasers of such pipe, the following conditions should be realized.

1. All bids would be made on the same basis as to materials to be employed, technique of fabrication, tests to be imposed and conditions generally to be met, and would, therefore, be more readily comparable than in the absence of conformity with such code.
2. Assuming all conditions and requirements of the code fully met, the purchaser would be assured of a product, representing in both design and fabrication, the best approved standards and practice of the day.
3. The preparation of a specification by the buyer will be greatly simplified, since, for all matters covered by the code, it will be sufficient to require conformity therewith, thus saving the specification in detail of these various matters.
4. The manufacturer would be assured that all bids

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* Presented at Western Regional Conference, AMERICAN WELDING SOCIETY, Los Angeles, California, March 23, 1938.

† Stanford University.

NOTE: Since a code of the character referred to in the present paper must be broadly acceptable to both the manufacturers and the users of large hydraulic pipe, the committee charged with the formulation of this code (W. F. Durand, *Chairman*, Stanford University, Calif.) will welcome discussion and suggestions on any of the points raised in the paper.

must be made on the same basis of requirements and that all work must meet the same program of tests and acceptance conditions.

Regarding the many questions which arise in connection with the preparation of such a code, the present paper will deal with only a selected few. Any general discussion of the entire subject would require a paper longer than the code itself.

Regarding item No. 1, the chief questions with regard to the materials to be employed relate to the grades of steel permissible for use in the construction of large hydraulic pipe and to the degree of premium or penalty which should attach to the use of the various grades, as applied through factors modifying the allowed joint efficiency, and as thus affecting the tonnage of steel required for the job. The present A. P. I.-A. S. M. E. code fixes 0.35 per cent as the upper carbon limit for any steel used for fusion welded pipe The question may arise as to whether this limit should stand or should be changed, and if so by how much and in which direction.

Again the same code permits the use of some ten different specifications of steel covering a much wider range of prospective use than appears likely in the construction of large hydraulic pipe. It seems possible that the number of specifications, under the code for such pipe, may be reduced considerably. And if so, the question arises as to which should be retained, and also as to whether others should be added. In particular, the question will arise as to the extent to which higher tensile strength steels may be employed without sensible hazard to the efficiency of our present welding technique.

The subject matter of No. 5.—rules for the design of the thickness of the shell—presents peculiar and interesting problems. The fixing of this dimension, more than anything else, determines the tonnage of steel which will be required for the line, and hence an all important item of its cost.

Usually the thickness in relation to diameter is such as to justify the use of the membrane formula—that is, the commonly accepted formula for the determination of the thickness of a thin cylindrical shell subjected to internal pressure. Cases may arise in which the influence of thickness should be considered; and in such cases the Lamé formula, as given in the code, may be accepted as satisfactory.

These formulas involve a factor "e," the efficiency of the joint. Advantage is taken of the presence of this factor, to give to it a sliding scale of values depending on the type of welded joint employed, the grade of steel to be used and the treatment technique following the welding of the joints. Thus, the standard A. P. I.-A. S. M. E. code gives a basic value depending on the grade of steel ranging from 1.00 to 0.92; again factors depending on the type of welded joint ranging from 0.80 to 0.65, combined with a possible factor of 1.12 for radiographing and of 1.06 for stress relieving. This gives a possible range of values for the joint efficiency as given in the A. P. I.-A. S. M. E. code ranging from 0.60 to 0.95. In the tentative draft under preparation, provision has been made for a third "treatment"—test by magna-flux which combined with radiographing has been allotted a tentative factor value of 1.15, making a possible maximum value of the joint efficiency of 0.975.

Now here, immediately enter two problems. Certain manufacturers feel that for the best grade of steel and a double welded butt joint, without further treatment by stress relieving, radiographing, etc., conditions of use may justify a value of the joint efficiency greater than the 0.80 which is now allowed by the A. P. I.-A. S. M. E. code. Thus, assume a pipe line across a stretch of desert country under conditions involving no sudden closure of change in the flow, and where even a break would involve no hazard to life and no serious hazard to property. It is urged, since test joints made under proper conditions may show joint efficiencies approaching and even reaching 100%, and since the allowed stress is calculated to provide a factor of safety of 2 based on yield point stress, that under these conditions a value of the joint efficiency greater than 80% should be allowed.

Again at the other end of the line, with the highest grade of steel, the most effective type of joint with the whole range of treatments after welding—stress relieving, radiographing, etc., and here continued tests of welds show joint efficiencies of 100%, it is urged that the factors referred to above should be so adjusted as to admit of 100% value for this program of full technique.

What the final proposals in such cases in the code under present discussion may be, remains for further discussion and consideration.

Another interesting question arises in connection with the manner in which the allowed working stress shall be related to the critical characteristic of the material. Until relatively recent years, the so-called ultimate strength was the critical value to which the allowable working stress was related. In recent times, however, the stress at yield point has gained ground as the critical standard and the present tentative draft of the code for large hydraulic pipe follows this method with a required ratio of not less than 2 to 1. With the grades of steel commonly employed for such purposes, this will give a factor of safety of about 2 on stress at yield point and a factor of about 4 on ultimate strength. Or otherwise, with steel of the grades commonly employed, this will allow a working stress of 14,000 to 15,000 lb., or with special steels, still permitting of entirely satisfactory treatment by modern welding technique, the working stress may be raised to 18,000 to 20,000 lb. per square inch, based on a stress at yield point of 38,000 to 40,000.

TREATMENT FACTORS FOR STRESS RELIEF, RADIOGRAPHING AND TESTING BY MAGNA-FLUX

The present A. P. I.-A. S. M. E. code recognizes only the first two of these treatments. The tentative draft for large hydraulic pipe adds magna-flux to the list combined with radiographing, and with a combined factor of 1.15 as compared with 1.12 for radiographing alone. The final value of these factors remains still a question open for consideration.

There is also the question whether testing by magna-flux alone should not be accepted for relatively thin plates, and thus given a factor of its own, independent of radiographing.

There is a further question of whether an attempt should be made in the code to define certain classes of work or certain conditions of operation for which some combination or all of these treatments would be required or whether their use should be made largely optional, the choice to be determined by the purchaser having in view the greater presumptive security and the reduced tonnage in the line as a result of these various "treatments" and of the increased joint efficiency which they will permit in the design.

The code must, of course, comprise full and clear directions with regard to the technique of these "treatments." The present A. P. I.-A. S. M. E. code already furnishes such directions for heat treatment and for radiographing. The code for large hydraulic pipe will contain these together with similar rules and directions regarding the technique of testing by magna-flux.

Passing over a large number of items, note may be made of the question of the whole routine of physical tests, based on test plates and in particular, of the length of welded joint of which each test plate may be taken as representative. Thus, the present A. P. I.-A. S. M. E code for unfired pressure vessels provides for plates over $1^1/_4$ inch in thickness, a round of tests for every 100 linear feet of weld, for plates between $1^1/_4$ inch and $^1/_2$ inch a round for every 200 feet and below $^1/_2$ inch, a round for every 300 feet.

Are tests with these degrees of frequency adequately representative of the quality of work in the joints, or would lesser frequencies be suitably representative? These are questions meriting careful consideration.

We may pass on next to the question of hydrostatic test. In such tests there are three principal items for consideration.

1. The relation of the test pressure to the design working pressure.
2. The length of time, the section of pipe or the line should be subjected to such pressure.
3. The question of the hammer test while the pipe is under the test pressure.

Regarding these items, the present tentative draft of code for large hydraulic pipe proposes a test pressure 50% over the design working pressure. This has been the general practice where such tests have been carried out, and it should serve to develop any latent defects or weakness in the pipe, while at the same time involving no danger of distress or of permanent strain to pipe properly designed, and of material and fabrication technique according to the code.

Regarding the length of time the pipe would be subjected to this pressure, it is a question whether any specific time should be required or whether the period should be expressed in more general terms as, e.g. "sufficient to permit a thorough and complete examination of the entire outer surface of the pipe with note and marking of any point where there may be exudation of moisture, pin hole leaks or evidence of distress or unsatisfactory conditions of any character whatever." Presumably something like the latter will be more satisfactory than the attempt to specify minimum times in precise measure for all cases and conditions.

Regarding the hammer test, the tentative draft for large hydraulic pipe omits such test. The reasons for such omission are the following.

The hammer test results in a sharp shock localized at one point on the shell, resulting in acoustic waves in the steel which may travel around the pipe in two directions, and meeting at some opposite point may there mutually reinforce, resulting in conditions of stress quite foreign to those to which the pipe should be subject in normal service. Or perhaps we may say more briefly, that the hammer test produces conditions which are not representative of those characteristic of normal service.

And again, it is our belief that the static test carried out with a 50% overpressure should be adequate to disclose any conditions involving a menance to the security of the pipe.

In this same connection, there is also the question of provision for the hydraulic test of a pipe line in the field after completion. If the line is level, or sensibly so, the same general rules may be applied as for the test of sections of pipe in the shop. If, however, as is often the case, the line has a marked gradient, as for a penstock line or a pump delivery line into an elevated reservoir, the question will immediately arise as to the interpretation of a 50% overpressure. In any case the line must be closed at the upper and lower boundaries of the part under test, such closure being effected either by a valve capable of standing the overpressure contemplated, or by a hemispherical or other type of bulkhead suitably secured in place. If then, the line being filled with water, overpressure is applied by pumping until the pressure at the lower end of the line is 50% in excess of the normal maximum working pressure at that point, then pressure at the upper end of the line will be in excess of 50% overload for that point by one half the difference between the normal pressures at the two ends of the line.

Thus for example, if the normal design pressure at the lower end is 100 pounds per square inch and at the upper end 50 pounds, and if a total pressure of 150 pounds is applied at the lower end, the pressure at the upper end will be 100 pounds instead of 75.

This situation is often helped by the fact that, to avoid hazard of collapse under excess external pressure and to give greater stiffness of form and greater strength as a beam between supports, as well as to provide for loss of metal by corrosion or wear, the thickness at and near the upper end of such lines is made thicker, sometimes in marked degree, then as called for by the requirements for strength alone. In such case the pressure at the lower end of the line may be raised to a point which will give 50% over normal pressure at the upper end with perhaps somewhat less than 50% over normal at the lower end. Where the difference in elevation of the two ends of the line is very great and a field test is required, the line should be tested in parts as it is erected, beginning at the bottom, the upper end of each new part being closed by a bulkhead. In this way, with a suitable number of parts, the entire line may be put under test pressures closely approximating to the 50% overload for each successive section of the line and thus a reasonably satisfactory test realized.

An important part of any welding code must deal with the subject of tests of any proposed welding technique, and with the tests of the welders to be employed on the work.

Reference has been made to the two codes now extant and applicable to unfired pressure vessels—the A. S. M. E. and the A. P. I. - A. S. M. E. codes. It is understood that a joint committee is now engaged in the task of fusing these two formulations into a single code and already there has appeared a tentative draft of the sections which bear on the subjects of tests of welding technique and of welders. These sections have been very carefully considered and appear to cover the ground very thoroughly. They are therefore, incorporated as a whole in the tentative draft of the code for large pipe for hydraulic use.

Reference may now be made to the general subject of the design of specials and of attachments, as noted under No. 6 of the general list of items which a code should comprise. No formulation of this part of the code for large hydraulic pipe has as yet been made. There is a large amount of material available in the two codes to which reference has been made.

However, the general plan of procedure with reference to the present code has been to formulate all parts except those relating to these highly specialized problems up to the point of issuance in tentative form for consideration, comment and criticism by the industry and by the buyers of such material. In the meantime a start will be made on the sections of the code relating to these special items, and this will then follow along in the same general course.

It will be sufficient here to note that many of these problems are highly complex in analytical character. Most of them defy attack by theory alone; at least it is not possible by analytical methods alone to obtain a complete and detailed knowledge of the amount, character and distribution of the stresses in such structures or in the

pipe near the point of attachment, though in many cases satisfactory approximations may be made.

The final result must, therefore, often depend on experience, or on special test adapted to disclose the results of particular conditions of service.

It is the hope of the Committee that with a combination of renewed analytical approach combined with the results of certain tests which have recently become available, that certain useful additions may be made to the present code material pertaining to these subjects.

DISCUSSION

By H. P. VAIL†

1. Dr. Durand's paper presents in brief, but quite complete form, the present status of the proposed Code for Large Welded Pipe. The need for such a code is pressing, and it is hoped that his committee will follow the matter diligently to the end that an approved Code will be available before the present boom in large construction projects is ended.

2. With respect to the design problems for large diameter steel pipe which faced the Metropolitan Water District a few years ago and which still face it in the somewhat smaller sizes, the need for reliable data on which to base thickness computations is great. Specifically I would like to see the Committee include in the Code the following matters which are either ignored entirely in the proposed draft or only touched on incidentally:

(1) What is the recommended design procedure for external backfill loads of various depths and with various kinds of soil?

(2) What is the relation between trench width, overburden, method and materials of backfill, live and dead load?

(3) How much out of round may the completed pipe line be and still constitute a satisfactory job from both the contractor's and owner's standpoint?

(4) What are the merits of ring girder stiffening as compared with thicker walled pipe for both buried and open construction?

(5) Can a recommendation be made on the relative merits of welded *vs.* riveted joints for gravity or pressure water pipes, penstocks and pump delivery lines?

(6) What is the recommended practice regarding the extra $^1/_{16}$-inch thickness added in many instances as a corrosion factor, in the light of modern coatings?

(7) What is the recommended practice with regard to the use of stulls to hold pipe round during erection and backfill, and is it considered desirable to put large water pipes under pressure before backfilling?

In connection with the above questions, the Metropolitan Water District has found that for a considerable portion of the length of steel pipes installed or to be installed the thickness is controlled, not by internal pressure, but by the somewhat arbitrary selection of minimum plate thickness based on the requirements of rigidity, and influenced appreciably by external loads. We have also found that rather large deflections have occurred in certain types of soil where the pipe is buried relatively deep, and the question arises as to whether such deflections are reasonable and harmless or unreasonable and hazardous. The need for experimental work on full size pipes is clearly indicated and it is hoped that some research program will be undertaken in an effort to find the answer to some of the questions which do not lend themselves to a direct mathematical analysis.

† Engineer, Distribution Division, The Metropolitan Water District of Southern California.

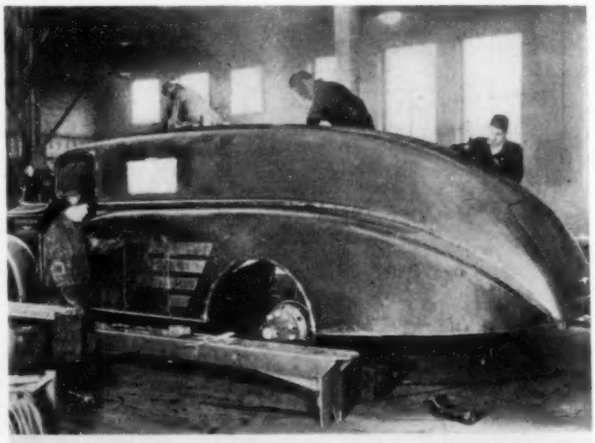
Gasoline Transport Tank Is Streamlined

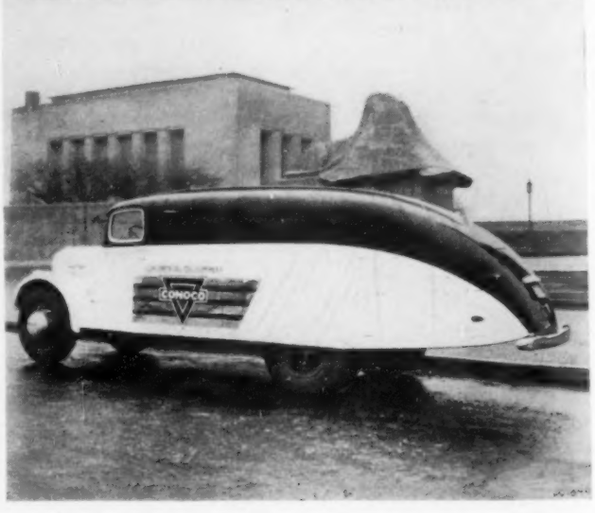
By A. F. DAVIS†

MOST people associate streamlining with pleasure cars and regard it as simply the designer's way of giving modern cars that "racey" appearance. That streamlining must and does have practical value is indicated by the increasing numbers of vehicles such as streamlined trains and buses. It conserves power and saves fuel by reducing wind resistance to a minimum.

The modern streamliner illustrated here is a thousand gallon gasoline transport tank truck built by the Columbian Steel Tank Company of Kansas City, Missouri for the Continental Oil Company. As in the case of so many other "streamliners" construction is arc welded. According to the builders, welding made the design of this particular body possible.

The Tank Under Construction by Electric Welding





The Thousand Gallon Gasoline Transport Tank Ready to Be Placed in Service

† Vice-President, The Lincoln Electric Co.

Welding Society ACTIVITIES—Related Events

1938 INTERNATIONAL OIL SHOW BREAKS ALL RECORDS

American Institute of Mining and Metallurgical Engineers had the honor of starting festivities. They held the first night's event dinner on the night of the 12th. President Daniel C. Jackling, San Francisco, and a party of guests were honored including H. G. Moulton, Cons. Engr. N. Y., A. B. Parsons, Secretary of the Institute, John M. Lovejoy, President Standard Oil Company, E. deGolyer, Dallas, former President Amerada, Petroleum Corp. and John R. Surnan, Vice-President of Humble Oil & Refining Company.

The National Oil Scouts Association of America held a record rally for the three days ending the 14th.

At 2:00 P.M. on the 14th the Show was formerly opened with a National Broadcast and suitable exercises, exploding bombs, etc. Speakers were Wm. G. Skelly, President of the Exposition and of Skelly Oil Company, Robert S. Keer, President, Kansas-Oklahoma Section of Mid Continent Oil and Gas Association, A. E. Barrit, President, Hudson Motor Company, Detroit and H. C. Merritt, Vice-President, Allis-Chalmers Mfg. Co., Milwaukee, and Governor Marland of Oklahoma.

Delegates were in attendance from all parts of the world and every major oil producing field was represented.

This 1938 Show was 50% bigger than former shows.

Over $10,000,000 worth of equipment being shown. The Hall of Science had $250,000 worth of models and scientific equipment. The Engineering Societies including AMERICAN WELDING SOCIETY, had their booth here. The Society Tulsa Section played host to visiting members with a dinner during the Show. Members from nearly every Section of the AMERICAN WELDING SOCIETY were present and the Managing Director from New York.

As one walked around the Show he was impressed with the part Welding plays in the Petroleum Industry. Practically all of the 1230 exhibits used Welding in some manner in the production of the 10,000 pieces of equipment which came from 148 cities and 29 states.

WELDING CHROME STEEL

The Harnischfeger Corporation of Milwaukee presents to the welding industry, Smootharc "Harchrome"—a new electrode designed exclusively for welding 4–6% chrome steel, depositing weld-metal which has the same properties as the parent metal.

DR. ELIHU THOMSON MANUSCRIPTS

The following communication has been received from the Library of the American Philosophical Society, 222 Drexel Building, Philadelphia, Pa.

Miss M. M. Kelly, *Secretary*,
AMERICAN WELDING SOCIETY,
33 West 39th Street,
New York City.

Dear Miss Kelly:

A short time after the death of Dr. Elihu Thomson the question was raised as to the disposition of the many papers, manuscript and printed, which he had accumulated during his long life with reference to his significant achievements. A suggestion was made to Mrs. Thomson and to Mr. Owen D. Young of the General Electric Company that the American Philosophical Society, due to the Doctor's long period of membership and interest in the Society, would be an appropriate place to permanently house such a collection. This plan received the hearty approval of Mrs. Thomson and the Doctor's sons as well as the executives of the General Electric Company.

Up to the present time there have been deposited with the Society about 2000 pieces of correspondence, both to and from Dr. Thomson, five volumes of the Doctor's manuscript comments on his numerous patents, an almost complete set of his many articles contributed to scientific periodicals, a number of letterbooks containing his correspondence during the early days of the General Electric Company and its forerunners and other miscellaneous items.

In order to make this collection as complete as possible we are writing to the many organizations of which Dr. Thomson was a member to ask that the membership be notified of this project. It is our hope that in this way many scattered pieces of Thomsoniana might be added to the material already here. The Society will be very glad to accept copies if the owners are loath to part with the original autographs.

Friends of Dr. Thomson anticipate that a biography of him will be written, and of course the more complete the file of papers the truer the picture of his life. Then too, looking ahead, it will facilitate the work of the future student of research in the history of the electrical industry to find the bulk of the material in one place rather than scattered far and wide.

The Society will be truely grateful for your cooperation in this work.

Very sincerely yours,
ROLAND S. MORRIS, *President*

DEDICATION OF ARTHUR NEWELL TALBOT LABORATORY

The dedication took place on April 21, 1938 in the University of Illinois Auditorium at 2:30 P.M. Melvin Lorenius Enger, Dean of the College of Engineering, presided. The Honorable Orville M. Karraker, a member of the Board presented a Statement of the Action of the Board of Trustees; Remarks on the Action of the Trustees were presented by Arthur Cutts Willard, President of the University and Response by Professor Arthur Newell Talbot. Robert Ernest Doberty, Illinois '09, President of Carnegie Institute of Technology presented an address on Technology, Education and Social Welfare. The Toastmaster was Herbert Fisher Moore, Research Professor of Engineering Materials.

SECTION SPEAKERS

National headquarters is compiling a list of available speakers for Section Meetings throughout the country. All companies and individuals desiring to present papers before Sections should promptly advise Society headquarters giving title of paper, author and preference as to Sections, if any. Any other pertinent information will be welcome.

COMMITTEE ON ADMISSION

In accordance with the new By-Laws, the President has appointed a Committee on Admission to Membership, the personnel of which is as follows: F. E. Rogers, *Chairman*, A. W. Carpenter, J. L. Edwards, Charles Kandel and S. S. Scott.

BRIDGE SPECIFICATIONS BEING REVISED

The Conference Committee consisting of representatives of the AMERICAN WELDING SOCIETY, the American Railway Engineering Association and the American Association of State Highway Officials, are now working on a revised edition of the Bridge Specifications. It is hoped that this will be ready sometime in early fall. Comments and criticisms on the present Specifications are respectfully requested. They should be addressed to W. Spraragen, Secretary of the Committee, % AMERICAN WELDING SOCIETY, 33 West 39th Street, New York.

STANDARD QUALIFICATION PROCEDURE

The AMERICAN WELDING SOCIETY has just issued a completely revised specification for the Qualification of Welding Processes and Welding Operators. This is arranged in an attractive thirty-page pamphlet. Price 25¢.

LINCOLN ESTABLISHES SUBSIDIARY IN AUSTRALIA

Mr. J. F. Lincoln, President, The Lincoln Electric Company, announces establishment of a manufacturing subsidiary to be called Lincoln Electric Company (Australia) Pty., Ltd., at Sydney, Australia. A suitable factory has already been purchased and arc welding equipment manufacturing operations will begin in a year's time.

J. F. Lincoln in Australia

Commenting on the establishment of the Australian plant, which he believes will increase the scope of welding throughout the commonwealth because of the increased speeds and lower costs made possible by the equipment to be built, Mr. Lincoln expresses great faith in Australia's industrial future.

While in Australia, Mr. Lincoln visited all the capital cities, giving a series of addresses before various engineering societies and groups on developments in the art of welding. Great interest in welding was indicated by the large enthusiastic attendance wherever he spoke. He is expected back in the United States in May, returning by way of South Africa and England.

WELDING CAN TAKE IT

One of the advantages found in the all-welded construction of steel hopper barges is demonstrated by this view of the damage resulting from collision with a lock wall. Damage was confined to the area shown, and the welded seams withstood the shock. Interior angle frames prevented extensive buckling of the deck plates, and transverse and longitudinal trusses in the rake end prevented damage to the bulkhead.

The barge after the accident, was towed stern foremost to its destination, Memphis, Tenn., unloaded, and then brought to the Dravo Corporation's Marine Ways, where it was repaired in a week's time at a cost of less than $2000.

NEW PIPE WELDING BULLETIN

Arc welding of piping for operation at pressures up to 1500 pounds per square inch and temperatures up to 1000° F. is covered in a new 12-page bulletin issued by the Metal & Thermit Corporation, 120 Broadway, New York, N. Y. In addition to the selection of pipe materials and welding electrodes, this bulletin discusses weld design, welding procedure, preheating, stress relieving, testing of welds and the qualification of welding process and welding operators.

SECTION ACTIVITIES

BIRMINGHAM

Birmingham Section held their last meeting for the 1937–38 Season, Tuesday, May 17th, at 8 P.M. in the Auditorium of the Alabama Power Company Building. One hundred forty three were present. Two mighty fine papers were presented on the following subjects:

"Safety—Fire Prevention in Welding and Cutting Industry," by J. I. Banash, Chicago, Ill., Consulting Engineer, International Acetylene Assn., Past-President, National Safety Council.

"Stainless Steel Welding" (Illustrated), by R. D. Thomas, Vice-President, Eastern Div., A.W.S., Arcos Corporation, Philadelphia.

After the presentation of the papers, installation of officers for 1938–39 season was held. They are as follows:

Chairman—A. C. Leigh, Ingalls Iron Works

Vice-Chairman—L. E. Cobb, Goslin-Birmingham Mfg. Co.

Secretary-Treasurer—W. L. Poole, Air Reduction Sales Co.

Executive Committee—two years:

E. E. Michaels, Chicago Bridge & Iron Works; J. E. Durstine, The Lincoln Electric Company; C. C. Pinkney, Birmingham Boiler & Eng. Co.; W. P. McCutcheon, Birmingham Electric Company; Paul Wright, Paul Wright Company; C. E. Korner, Alabama School of Trades.

BOSTON

The following Officers were elected for the year 1938–39 for the Boston Section:

Chairman—P. J. Horgan, General Electric Co.

Vice-Chairman—W. L. Warner, Watertown Arsenal.

Secretary-Treasurer—P. N. Rugg, Boston Edison Co.

Directors for two years: C. H. E. Coster, Worcester Boys Trade School, L. Gordon, Hobart Bros. Co., S. J. Slater, Air Reduction Sales Co.

Trustee—A. L. Combs, The Linde Air Products Co.

CHATTANOOGA

The Chattanooga Section of the AMERICAN WELDING SOCIETY held their regular meeting May 18th at the Hotel Patten. The program as arranged by Mr. Mark Holt of the Chattanooga Welding & Machine Company was very interesting.

The subject presented by Mr. R. D. Thomas of the Arcos Corporation of Philadelphia was exceptionally instructive. He brought out enlightening points about the development of Stainless Steels and their rapid and wide spread application to many industries.

One highlight of the talk was the significant delicate structure of metal crystals of which stainless steel is composed. These various grain structures and their relation to polish, strength, ductility, hardness, etc. show a living mass under heat treatment working to obtain definite shapes and sizes.

It was shown that welding and its rapid progress has brought definite demands on the steel industries to produce steel that will react to welding as the chemist expects his solutions to react in definite proportions.

The local section of the AMERICAN WELDING SOCIETY has planned a future program to which any who may be interested may attend. The next meeting will be held next month at which time the Ross-Meehan Foundries will show the application of welding of castings of special composition.

CHICAGO

The regular monthly meeting of the Chicago Section was held on Friday, May 20th at the Skyline Athletic Club. "Welding the Stainless Steels" was discussed by T. R. Lichtenwalter, Welding Engineer, Republic Steel Corp., and E. J. Brady, Research Engineer, Hollup Corporation.

CONNECTICUT

Dinner meetings, a Christmas party and a new technique to be employed in a membership drive, are a part of the plans for the coming 1938–39 year of the Connecticut Section as discussed at the April meeting of the Executive Committee. Chairman E. R. Fish is pushing plans for next year already so that our Section can help accomplish the high aims of the AMERICAN WELDING SOCIETY.

Mr. H. R. Bullock of the Mass. Institute of Technology gave the Section an excellent talk on the "Weldability of Various Materials" on May 10th at Yale University. Of interest was the number of requests for membership after the address, which in itself is testimony of the interest which Mr. Bullock created.

DETROIT

At the April meeting, which was held on the 22nd, at the Detroit-Leland Hotel, Mr. R. T. Gillette, Works Laboratory,

General Electric Company, discussed "Solving Practical Problems in Resistance Welding." Mr. Gillette gave a very helpful discourse and together with slides and specimens showed many interesting problems of seam, spot and interrupted spot-welding applications.

The May meeting, held on the 20th, in the Colonial Room of the Detroit-Leland Hotel, was addressed by Mr. Albert S. Low, Vice-President and Chief Engineer of The Austin Company, whose subject was "Welded Construction in Some Recent Industrial Buildings." Mr. Low discussed the "tree-form" column which supports saw-tooth roof members without intermediate bracing, which has been used in the Lincoln Electric Company's new 200,000 square foot plant, construction of which was described by Mr. Low in conjunction with motion pictures showing the work in progress.

GEORGIA

The Georgia Section held its regular monthly meeting in the Henry Grady Hotel on April 22nd. Mr. D. B. Hunt, Welding Engineer of the Southern Railway Company, conducted the meeting which consisted principally of questions and answers. Every one present at the meeting seemed to be highly interested in the questions and answers and all had some question to ask regarding some certain application. Each question was answered in full detail by either Mr. Hull or some member present.

Mr. G. D. Barr is Acting Secretary of the Section due to the transfer of the Secretary, R. G. Wilson, to Chicago.

INDIANAPOLIS

The closing meeting of the season was held on May 5th at Athenaeum. Mr. Robert F. Flood, Service Engineer of The Linde Air Products Company, presented a very interesting address on "Oxy-Acetylene Cutting & Treating Processes as Applied to Welded Fabrication."

KANSAS CITY

The April meeting of the Kansas City Section was held on the 25th. Mr. Wm. B. Brady, General Electric Company, addressed the meeting on "Rail Flash Welding." A moving picture illustrating this talk was also shown.

MARYLAND

"Arc Welding Around the World" was the subject of the address presented by Mr. A. F. Davis of The Lincoln Electric Company at the April 8th meeting which was held at the Engineers' Club. Mr. Davis' talk covered welding conditions in all parts of the world and the meeting was very well attended.

The Nominating Committee announced the following officers and members of the Executive Committee for the season 1938–39:

Chairman—C. N. Hilbinger, T. A. Canty, Inc., 1023 Cathedral St., Baltimore.

Vice-Chairman—Leo Gould, Bethlehem Steel Corp., Sparrows Point, Md.

Secy.-Treas.—Roy A. Mansfield, Southern Oxygen Co., 144 W. Hamburg St., Baltimore.

Members of Executive Committee to serve for three years: M. G. Wicker, Air Reduction Sales Co., Baltimore; John C. Cumberland, Arcway Equipment Co., Baltimore.

MONTANA

The Montana Section announces the election of the following officers:

Chairman—Adolph F. Chan, Nashua, Montana.

Vice-Chairman—W. M. Galloway, Nashua, Montana.

Secy.-Treas.—C. F. Garmon, P. O. Box 474, Fort Peck, Mont.

Executive Committee (Users)—Harry S. Griffith and Elmer E. Seals (Commercial)—Lee Reay and H. W. Wolfe.

NEW YORK

A combined business meeting and get-together of the New York Section will be held on June 14th.

NORTHWEST

"Fusion Welding, Where It Has Been and Where It Is Going" was the subject of the April 28th meeting of the Northwest Section, by Mr. W. D. Halsey, Asst. Chief Engineer, Boiler Division, The Hartford Steam Boiler Inspection & Insurance Company. Mr. Halsey's talk was illustrated by lantern slides.

On April 29th and 30th, 1938 the National Bushing & Parts Company of St. Paul and Minneapolis, and The Lincoln Electric Company, sponsored an "Electric Welding Demonstration and Exhibition" at the Mack Truck Building, 2505 University Avenue, St. Paul, which was largely attended. Among other features, there was an exhibition of all sizes of welders, both electric and gasoline driven models, a display of welded parts by manufacturers in the Twin City area, and a demonstration of welding electrodes on various types of metals. Welding problems were discussed and many questions were answered as to the operation of welders and electrodes.

"Spot Welding" was the subject of the May 19th meeting, presented by Mr. F. L. Damarin of the P. R. Mallory & Co., Inc. Following Mr. Damarin's talk which was illustrated by lantern slides, there was a lively discussion

The following officers and members of the Executive Committee were elected to serve for the ensuing year:

Chairman—John Nelson, Butler Manufacturing Co.

Vice-Chairman—Wm. E. Murphy, Northern States Power Co.

Secretary-Treasurer—Alexis Caswell, Manufacturers' Assn. of Minneapolis, Inc.

Executive Committee—C. M. Akins, Marquette Manufacturing Company; J. H. Barron, Brown Sheet Iron & Steel Co.; C. E. Comfort, St. Paul Structural Steel Co.; T. P. Hughes, University of Minnesota; G. W. Irwin, Air Reduction Sales Company; Amos Johnson, Commercial Gas Co.; E. R. Johnson, Westinghouse Elec. & Mfg. Co.; Fred Klass, General Electric Company; H. A. Lindeke, Nicols, Dean & Gregg; R. H. Newton, The Lincoln Electric Company; R. W. Robinson, American Bridge Company; T. J. Warmington, Wm. Bros. Boiler & Mfg. Co.; G. V. Watson, Flour City Welding Company; J. E. Williams, The Linde Air Products Co.

OKLAHOMA CITY

The Oklahoma City Section has completed its first lecture course consisting of five lectures three of which have been previously reported.

The remaining two lectures were given April 14th and April 21st, the subject being "Inspection of Welds and Method of Testing" and "Structural Welding," respectively. These subjects were well presented by J. L. Owen, Inspector of the Hartford Steam Boiler Inspection and Insurance Company, handling the first subject and L. E. Acker, Engineer, with J. B. Klien, Iron and Foundry Company, as the speaker and also as the leader of the discussion on the other subjects.

All five lectures in the series were well attended. Three of the lectures were closed lectures, that is, for members only and the other two lectures were open to members and friends, and on the basis of attendance as well as the interest manifested in the discussion following the various lectures, the Committee and the Officers feel well repaid for the effort put forth in promoting and arranging this lecture series.

The regular monthly meeting for May was held on the second Tuesday or May 10th instead of the regular meeting night, the first Tuesday, in order to accommodate the schedule of the guest speaker.

Mr. Frank Cusson of the Hollup Corporation was the speaker of the evening and gave a very interesting talk on "General Welding Application" the talk being illustrated by lantern slides. Mr. Cusson's talk brought out that many foundries have arranged to amalgamate steel castings and fabricated parts which formerly were made of castings, thus the companies still handle about the same tonnage but instead of being all castings the tonnage is now divided between castings and fabricated material consisting of heavy plates and sections.

Mr. Hays, Managing Director of the Society, spoke of the activities of other sections, outlined some of the changes in the By-Laws and gave us a general idea of the aims of the Society.

For the opening feature of the meeting a moving picture showing the flash welding of rails was presented through the courtesy of the General Electric Company.

The meeting was adjourned at 9:40 after which a half hour of sociability was enjoyed mixing conversation with soft drinks, Oklahoma legal brew and crackers and pretzels.

PHILADELPHIA

The following Officers have been elected by the Philadelphia Section:

Chairman—Ed G. Hosted, Drexel Institute.

Vice-Chairman—H. R. Salisbury, Air Reduction Sales Co.

Treasurer—R. D. Thomas, Arcos Corp.
Secretary—H. E. Hopkins, Arcos Corp.

The Annual Inspection Trip of the Philadelphia Section was held on May 18th. A personally conducted educational tour was made through the mills of the Worth Steel Company, Claymont, Delaware. The visitors were shown the process of making steel from raw material to finished plate in this modern plate mill.

PITTSBURGH

The Tri-State Welding Conference sponsored by the Pittsburgh Section of the A. W. S. jointly with the Engineers Society of Western Pennsylvania was held Friday afternoon and evening, April 29th in the Blue Room and Gold Room of the William Penn Hotel, Pittsburgh, Pa. and was a marked success.

At the afternoon session standing room was at a premium and many late arrivals were forced to stand or listen from without the doorways.

Robert E. Kinkead, Consulting Engineer, Welding, Cleveland, Ohio gave an exceptionally brilliant talk on the subject of "Welding in the Production of Steel." Mr. Kinkead reviewed welding in all its phases in the many different kinds of steel and was extremely interesting to many representatives from the various industrial plants in this region.

Mr. Albert S. Low, Vice-President and Chief Engineer of the Austin Company spoke on the subject "WELDED CONSTRUCTION IN SOME RECENT INDUSTRIAL BUILDINGS" and illustrated his talk with both moving pictures and still views of many interesting industrial buildings fabricated and erected by his company. In addition he had with him many photographs of the work and some samples of weld tests made in his factory. Following his talk, Mr. Low was deluged with many questions from the floor and it was with some difficulty that the discussions could be closed in order to permit the showing of motion pictures by Mr. C. I. MacGuffie, Arc Welding Specialist, General Electric Company, Philadelphia, Pa. who showed films of "The Flash Welding of Rails" and "Welding Arcs."

In the evening Mr. P. G. Lang, Jr., President of the Society and Engineer of Bridges, Baltimore & Ohio Railroad, Baltimore, Maryland, gave a very interesting talk on the AMERICAN WELDING SOCIETY and reviewed the work done during the past year and commented on the prospect for future development in building up of the Society into one of the outstanding technical associations of the country.

Mr. A. E. Gibson, President, Wellman Engineering Company, Cleveland, Ohio and Past-President of the AMERICAN WELDING SOCIETY discussed many interesting welded fabrications of his company and illustrated his talk with motion pictures showing in detail the manner in which his work is being done.

The principal speaker at the evening session was Mr. H. C. Hettelsater, Executive Engineer, Harnischfeger Corporation, Milwaukee, Wis. who talked on "Welding in the Construction of Cranes and Power Excavators. Following his paper many questions were asked from the floor and Mr. Hettelsater and his Chief Engineer, Mr. Hansen, were kept busy replying to them.

Between sessions an informal get-together dinner was held and sixty-eight of those present at the meetings attended. Many old acquaintances were afforded an opportunity to meet again and discuss old times.

The committee in charge of the Conference were especially well pleased with the results obtained in this, their first Welding Conference, and it was the unanimous opinion that it should become an annual affair.

SAN JOAQUIN VALLEY

Fifty members and guests attended and enjoyed a most interesting program at the April 21st meeting of the San Joaquin Valley Section. Mr. T. R. Walther, District Manager, The Linde Air Products Company presented an illustrated paper on "Alloying Elements in Welding Rods." An illustrated lecture on Aerial Photography by Mr. C. Bicklham of the Fairchilds Aerial Surveys Co., clarified much of the mystery surrounding the art of aerial photography and presented some of the many hazards attendant on such occupation. A Sound Film on "Rubber Insulated Cables," recently released by the Okonite Callender Co. of New York and San Francisco, showed the manufacture of rubber covered cables.

ST. LOUIS

The regular monthly meeting of the St. Louis Section was held at the Engineers' Club Auditorium Friday, May, 13th. One hundred and twenty-one guests and members heard Mr. H. C. Boardman, Research Engineer, Chicago Bridge & Iron Company, deliver a most interesting talk on the "Welding of Large Tanks of Spherical, Spheroidal and Cylindrical Shapes." Mr. Boardman's talk was illustrated by lantern slides of which many were in color.

A gala party is planned for the Section's annual meeting June 10th. The party will be held at the York Hotel and will consist of a dinner, meeting and entertainment afterward. Out-of-town visitors are invited to attend. For reservations call or write Secretary C. W. S. Sammelman, % Engineers' Club, St. Louis, Mo.

SOUTH TEXAS

Mr. Albert S. Low, Vice-President and Chief Engineer of The Austin Company, gave an illustrated lecture on the "Arc Welding of Tall Buildings" at The Lincoln Electric Company's series of lectures, on May 13th in the M & M Building Auditorium, Houston. The Lincoln Electric Company, through their representative, the Big Three Welding & Equipment Company, extended an invitation to all members of the South Texas Section to attend this lecture.

TULSA

A picture showing reclamation of Stanolind Pipe Line from Casper, Wyoming to Freeman, Missouri was shown with lectures by J. E. Stirling, Engineer, and A. M. Hill, Welding Superintendent of the Stanolind Pipe Line Co., at the April 29th meeting of the Tulsa Section. About fifty-five people attended the dinner, with an additional forty at picture attendance.

WICHITA

A very satisfactory meeting of the Wichita Section was held on April 29th at which Mr. Orville T. Barnett, Metallurgist for Black-Sivalls & Bryson, Inc., spoke on the subject "The Effect of Welding Heat on Mild Steel." The meeting was attended by 80 members and guests and seemingly the subject was interesting to every man present. Mr. Oren T. Helvey, Air Reduction Sales Company and Chairman of the Safety Committee, gave a short talk on safety which was very interesting and instructive.

Mr. H. C. Boardman of the Chicago Bridge & Iron Company was the speaker at the May 23rd meeting. His talk was illustrated with slides.

COLORADO—PROPOSED SECTION

At an organization meeting held in April the proposed Colorado Section elected the following officers:

Chairman—G. H. Garrett, Chief Engineer, The Thompson Mfg. Co., Denver.

Vice-Chairman—M. R. Nelson, Supt., General Iron Works.

Secy.-Treas.—Dan Ormsbee, Engineer, R. Hardesty Mfg. Co.

AMERICAN TRANSIT ASSOCIATION

The 57th Annual Convention of the American Transit Association, previously scheduled to be held in Atlantic City with an exhibit on September 19th–22nd, will now be held without an exhibit at the Royal York Hotel, Toronto, Ontario, on October 3rd–6th, inclusive.

This change in plans was announced by the Association's Executive Committee, following a meeting in Washington, D. C., on May 4th, in which manufacturer members of the Association recommended elimination of the exhibit from the 1938 Annual Convention program.

NEW PIPING COMMITTEE APPOINTED

The AMERICAN WELDING SOCIETY has appointed a Pressure Piping Committee whose personnel are identical with the A. S. A. Subcommittee on Welding for Pressure Piping. The personnel of the new Committee is as follows:

W. D. Halsey, Chairman	A. M. Houser
A. B. Bagsar	A. L. Penniman, Jr.
R. W. Clark	Alexander Kidd
D. H. Corey	D. S. Jacobus
T. W. Greene	N. L. Mochel
F. C. Fantz	G. O. Carter
B. Robinoff	J. J. Crowe
	L. R. Hodell

J. H. Williams

TENTATIVE PROGRAM

ANNUAL MEETING
AMERICAN WELDING SOCIETY
DETROIT, MICH., OCTOBER 16 TO 21, 1938

BOOK-CADILLAC HOTEL

PRESIDENT'S RECEPTION **Sunday, October 16th** Afternoon—5 to 7 P.M.

MONDAY, OCTOBER 17th, Morning—9:30 A.M.

Address of Welcome, by **RICHARD W. READING**
Mayor of City of Detroit

PRESENTATION OF MEDALS

TECHNICAL SESSION

Chairman, P. G. Lang, Jr.
The Baltimore and Ohio Railroad

Vice-Chairman, C. A. McCune
Magnaflux Corporation

WELDING IN CONSTRUCTION WORK

The Oxyacetylene Welding of Carbon Molybdenum Steel Pipe, **by A. N. KUGLER, Applied Engineering Dept., Air Reduction Sales Company**

Application of Unionmelt Process in the "Q-Weld" Procedure of Welding Heat Exchangers, **by R. M. WALLACE,** Asst. Supt., **The Griscom Russell Company**

Welding Structures, **by ALBERT S. LOW,** Vice-President, **The Austin Company**

SIMULTANEOUS TECHNICAL SESSIONS

Afternoon—2:00 P.M.

Chairman, K. L. Hansen
Harnischfeger Corporation

Vice-Chairman, F. E. Rogers
Air Reduction Sales Company

PRODUCTION WELDING SMALL MACHINE PARTS

Welding, Cutting and Machine Design of Small Sub-Assemblies, **by EDWARD J. DE WITT,** Vice-Pres., **Wallace Supplies Mfg. Company.**

Welding as Applied to Fabrication of Industrial Stokers, **by F. R. MASON, Riley Stoker Corp.**

Methods for the Manufacture of Precision Assemblies by Resistance Welding, **by F. D. ROGERS, International Business Machines Corp.**

Arc Welding as Influenced by Shop Preparation, Tools, Jigs and Fixtures, **by M. S. EVANS, American Car & Foundry Company.**

Chairman, Col. G. F. Jenks
Ord. Dept. U. S. Army

Vice-Chairman, E. Vom Steeg, Jr.
General Electric Company

INDUSTRIAL RESEARCH SESSION

Physical and Chemical Properties of the Nickel-Iron Alloys Formed in the Welding of Nickel Clad Steel, **by W. G. THEISINGER, Lukens Steel Co., J. H. DEPPELER, Metal & Thermit Corp., and F. G. FLOCKE, International Nickel Co.**

Weldability of Medium Carbon Steels, **by R. W. EMERSON, Westinghouse Elec. & Mfg. Co.**

The Effect of Current, Pressure and Time on the Shear Strength and Structure of Spot Welds in the Aluminum Alloys, **by G. O. HOGLUND and G. S. BERNARD, JR., Aluminum Company of America.**

An Investigation of Arc and Gas Welded Joints in Aluminum and Aluminum Alloys, **by Lieutenant Commander R. K. WELLS (CC) U. S. N. and A. G. BISSELL, Bureau of Construction and Repair, Navy Dept.**

TUESDAY, OCTOBER 18th, Morning—9:30 A.M.

SIMULTANEOUS TECHNICAL SESSIONS

Chairman, E. A. Balsley
Link Belt Company

Vice-Chairman, P. J. Horgan,
General Electric Company

WELDING AND CUTTING PROCESSES

Flame Cutting, **by J. J. CROWE, Air Reduction Sales Company.**

Bi-Metal Construction of High Temperature Steel Valves. **Author to be announced.**

Weld Penetration, **by JOHN HRUSKA, Chief Metallurgist, Electro-Motive Corp.**

Bronze-Welding, **by W. S. WALKER, The Linde Air Products Company.**

Chairman, A. B. Kinzel
Union Carbide and Carbon Research Laboratories, Inc.

Vice-Chairman, Milton Male
U. S. Steel Corporation of Delaware

FUNDAMENTAL RESEARCH SESSION

Fatigue of Welded Connections, **by S. C. HOLLISTER, Cornell University.**

Effect of Rigid Beam-Column Connections on Column Stresses, **by INGE LYSE and E. H. MOUNT, Lehigh University.**

Residual Stresses Due to Circumferential Welds in Pipes, **by E. L. ERIKSEN, University of Michigan.**

Some Electrical Characteristics of Arc, **by Dr. C. G. SUITS, Research Laboratory, General Electric Company.**

Afternoon—2:00 P.M.

SIMULTANEOUS TECHNICAL SESSIONS

Vice-Chairman, C. W. Obert
Union Carbide and Carbon Res. Labs.

JOINT SESSION WITH AMERICAN SOCIETY OF MECHANICAL ENGINEERS

Welding of Ammonia Containers. **Author to be announced.**

Brazing Tubes in High-Pressure Boilers with Silver Alloys, **by A. W. WEIR, New York Central Railroad and H. M. WEBBER, General Electric Co.**

Welding Bronze and Non-Ferrous Alloy Piping, **by H. D. LANTERMAN, Carbide and Carbon Chemicals Corp.**

Effect of Different Preheating and Annealing Temperatures on Welded Carbon Molybdenum Piping, **by R. W. CLARK, General Electric Company.**

Chairman, J. J. Crowe
Air Reduction Sales Company

Vice-Chairman, E. R. Benedict
Contract Welders, Inc.

FUNDAMENTAL RESEARCH SESSION

Weld Quench Test for Weldability of Steels, **by W. H. BRUCKNER, University of Illinois.**

Metallurgical Aspects of Resistance Welding Electrodes, **by DR. R. H. HARRINGTON, Research Laboratory, General Electric Company.**

Creep Test of Arc Welded Low Carbon Steel, **by N. F. WARD, University of California.**

Evening—**Fundamental Research Conference**

—— WEDNESDAY, OCTOBER 19th, Morning—9:30 A.M. ——

SIMULTANEOUS TECHNICAL SESSIONS

Chairman, Everett Chapman
Lukenweld, Inc.

Vice-Chairman, W. W. Petry
The Cincinnati Milling Machine Company

WELDING IN MACHINE DESIGN

Recent Developments in Welding of Machine Tool Structures, **by L. F. NENNINGER**, Chief Engineer, **and W. A. MADDOX**, Welding Supervisor, **The Cincinnati Milling Machine Company.**

Machine Flame Cutting with Small Machines, **by OTTO C. VOSS, Allis-Chalmers Mfg. Co.**

Welding and Cutting in Machinery Construction, **by J. GORDON**, General Manager, **Taylor Winfield Corp.**

Chairman, H. C. Jennison
American Brass Company

Vice-Chairman, W. M. Hayes
Air Reduction Sales Co.

INDUSTRIAL RESEARCH SESSION—Symposium on Copper Alloy Welding.

Progress in Copper Welding, **by IRA T. HOOK**, Research Engineer, **and CLINTON E. SWIFT**, Welding Engineer, **American Brass Company**

Testing of Spot Welds on Copper-Base Alloys, **by D. K. CRAMPTON, M. L. WOOD and J. C. BABIN, Chase Brass and Copper Co.**

Carbon Arc Welding of Silicon Bronze, **by E. S. BUNN and J. R. HUNTER, Revere Copper and Brass, Inc.**

A Quick Shop Test for Quality of Weld and Its Correlation with the Standard Tests, **by W. J. CONLEY, The University of Rochester.**

Afternoon—**Exhibits**

—— THURSDAY, OCTOBER 20th, Morning—9:30 A.M. ——

Chairman, Walter Anderson
Taylor Winfield Corporation

AUTOMOTIVE SESSION

Flame Hardening with the Oxy-Acetylene Flame, **by H. J. SHEPPERD**, Chief Metallurgist, **Kelsey Hayes Wheel Co.**

Vice-Chairman, C. L. Eksergian
Budd Wheel Company

Body Welding. **Author to be announced.**

Welding of Rear Axle Housings, **by E. L. BAILEY and V. KNECHT, Chrysler Corporation.**

Afternoon—2:00 P. M.

Chairman, Vaughan Reid
City Pattern Works

AUTOMOTIVE SESSION

Resistance Welding in the Automotive Industry, **by A. DI GIULIO, Ford Motor Company.**

Automatic Carbon Arc Welding in the Automotive Industry, **by F. M. MAICHLE, The Lincoln Electric Company.**

Vice-Chairman, A. S. Douglass
The Detroit Edison Company

Use of Welding in Reconditioning Used Cars, **by T. W. MOSS, Chrysler Motors Service.**

Evening—**Dinner**—7:00 P.M.

HARVEY CAMPBELL, Toastmaster, **Detroit Board of Commerce.**

Principal Speaker, **W. J. CAMERON, Ford Motor Company.**

—— FRIDAY, OCTOBER 21st, Morning—9:30 A.M. ——

SIMULTANEOUS TECHNICAL SESSIONS

Chairman, A. G. Bissell
Bureau of Construction & Repair, Navy Department

Vice-Chairman, S. S. Scott
Brooklyn Navy Yard

SHIP SESSION

All-Welded Steel Power Boats, **by MILO BAILEY, Bailey Steel Shipbuilding Co.**

Erection Sequence and Welding Procedure of All-Welded Lake Freighters, **by RUSSELL BRENDLE, Great Lakes Engineering Works.**

Welding Coast Guard Vessels. **Author to be announced.**

Chairman, H. C. Boardman
Chicago Bridge & Iron Company

Vice-Chairman, A. G. Oehler
Railway Age

RAILROAD SESSION

Welding in Car Construction, **by A. M. UNGER, Pullman-Standard Car Mfg. Co.**

Flash Welding of Rails, **by H. C. DRAKE, Sperry Products, Inc.**

BUSINESS MEETING—Election of Officers; President's Report; Board Luncheon

Afternoon—**Exhibits and Inspection Trips**

Optional trips will be arranged to any of the following companies:
Ford Motor Company; Cadillac Motor Company; Chrysler Corporation.

NEW SECTIONS IN THE MAKING!

Our Managing Director reports from the field that several new areas are blossoming forth into Sections of the Society, through the cooperation and interest of many loyal members and others recognizing the need and value of making the services of the Society available to more people.

E. B. Ellis of Ellis Supply Company, Jackson, Mississippi, held an outdoor meeting of some 40 men in his new shop under construction, on May 2nd. The new City Building Code was being passed at that time and Building Inspector Martin, told about steps for qualifying welders and other details necessary for the approval and acceptance of welding work. Mr. J. M. Griser is planning with Mr. Pettit for an organization meeting and development of a section in Mobile, Alabama.

On May 5th, the New Orleans group held an interesting meeting at which moving pictures were shown by Mr. Helper of The Linde Air Products Company on machine cutting and flame hardening. Mr. Vic Leveau of Liberty Welding Works, was named Temporary Secretary, and a membership committee appointed to complete the charter roll of this section promptly.

On May 6th at the conclusion of a splendid lecture course under the auspices of the Texas A & M College at Arlington and the Big Three Welding Equipment Company, given by E. W. P. Smith of the Lincoln Electric Company, at which 120 attended, it was decided to form the North Texas section. Mr. Walter Van Wart of Wyatt Metal & Tank Works, is Temporary Chairman, and Mr. Lloyd Welch of Southwestern Laboratories is Temporary Secretary. A final organization meeting and lecture is contemplated in late May or early June.

Central Illinois, under the leadership of Mr. Elmer E. Isgren, of R. B. LeTourneau, Inc., as Chairman, will shortly become a section following preliminary meetings of key men in late April, arranged by Temporary Secretary Bill Miskoe.

Nearly 200 attended the April 28th meeting at the Engineers' Club in Dayton, Ohio, to hear Messrs. Harris and Weiger repeat their fine talks and discussion of "Theory and Practice of Resistance Welding." Mr. Stansel and Mr. Meacham and this organization committee secured pledges that night which if promptly followed by necessary applications and checks will complete the Miami Valley section in May.

Western Michigan held its second meeting on April 18th, when a crowd of over 100 welcomed guest chairman Vaughn Reid of the Detroit section, who brought a delegation with him, including past chairmen of Detroit section John Tebbens and William Hayes. Those present enthusiastically endorsed plans and selected organization committee to assist Temporary Secretary R. D. Layman in completing a charter roll for this new section.

The same loyal A. W. S. members in Detroit journeyed to Toledo on April 27th to be present at a meeting arranged by Jack Shugars. The Toledo Committee has now become organized and hopes to complete this section shortly.

Following the fine meeting in Rock Island of February 28th, H. C. Kelsey of Machinery & Welder Corporation, Moline, arranged a meeting on April 26th and assisted by Messrs. Burgston and Swiedom, put on an interesting program. Those present, nearly 50, pledged enough support and help to enable the committee to conclude the formation of a Quad-Cities section in May.

A PRESSURE REGULATOR BULLETIN

An illustrated and comprehensive 26 page bulletin covering pressure regulators has just been issued by the Welding Equipment Division of Victor Equipment Company, 844 Folsom Street, San Francisco.

This bulletin contains three-color pictures of cut open single and two-stage VICTOR regulators; offers full details in regard to regulator design, construction and working principles, as well as flow charts showing per minute delivery volume of various VICTOR regulator models over their complete delivery pressure ranges. Six photographic reproductions illustrate principal regulator maintenance procedures and an ingenious tabulation sheet, folding out of the bulletin, makes comparative facts pertaining to regulator sizes, weights, delivery volumes, pressure ranges, diaphragm diameters, gage types and diameters and the gases for which they are designed instantly available.

This particular edition is limited because it contains considerably more data than is customarily compiled in this type of printed matter.

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List of New Members

April 1 to April 30, 1938

BOSTON

Demars, Arthur J. (C), 9 Centre St., Brookline, Mass.
Shea, Daniel F. (D), 7 Ardmore St., E. Braintree, Mass.
Woodrough, Kendal A. (C), 72 Arlington St., Newton, Mass.

CHICAGO

Alt, William (D), 7209 Rhodes Ave., Chicago, Ill.
Craemer, L. F. (D), 6244 S. Parkway, Apt. 309, Chicago, Ill.
Fentress, D. Wendell (B), Chicago Metal Hose Corp., Maywood, Ill.
Holt, R. W. (B), 10257 Torrence Ave., Chicago, Ill.
Hyland, Richard M. (C), 9 So. Clinton St., Chicago, Ill.

CLEVELAND

Shadrake, Bolick J. (B), 3238 W. 115th St., Cleveland, Ohio.
Trace, H. B. (C), Erie R. R. Co., 814 Republic Bldg., Cleveland, Ohio.

COLUMBUS

Foust, J. A. (B), 2333 Neil Ave., Columbus, Ohio.
Sloane, P. C. (B), 328 E. 18th Ave., Columbus, Ohio.
Tarrier, F. A. (B), The Tarrier Steel Co., 762 Hanford St., Columbus, Ohio.

CONNECTICUT

Anderson, Ernest A. (D), 12 Shoreham Terrace, Fairfield, Conn.

DETROIT

Clark, L. W. (C), The Detroit Edison Co., 2000 Second Ave., Detroit, Mich.

INDIANAPOLIS

Viewegh, Max (D), 115 No. De Quincey St., Indianapolis, Ind.

KANSAS CITY

Anderson, Bror Algot (D), 3157 Pennsylvania, Kansas City, Mo.
Dishman, Chas. H. (C), 1209 R. A. Long Bldg., Kansas City, Mo.
Morgan, L. L. (C), Puritan Compressed Gas. Corp., 2012 Grand Ave., Kansas City, Mo.
Rice, S. B. (C), 2400 N. 35th St., Kansas City, Kansas.
Smithus, Joseph (C), 1209 R. A. Long Bldg., Kansas City, Mo.

LOS ANGELES

Branzhaf, E. (C), Steel Union, Inc., 464 Chamber of Commerce Bldg., Los Angeles, Calif.
Barnett, Eric (C), Box 510, Arcade Sta., Los Angeles, Calif.
Burton, Claude E. (D), 1127 W. 18th St., Los Angeles, Calif.
Cleghorn, W. D. (C), 520 So. Anderson St., Los Angeles, Calif.
Foster, Ernest E. (D), 124 N. Atlantic, Monterey Park, Calif.
Lauterbom, Roy W. (D), 145 E. 77th St., Los Angeles, Calif.
Mariette, E. H. (D), 2902 Paola Ave., Los Angeles, Calif.
Mariette, Robert L. (D), 229 So. Chicago, Los Angeles, Calif.
Moyer, Daniel E. (F), Rt. 1, Box 1405, Tujunga, Calif.
Richardson, John Lyman (C), 4364½ Melrose Ave., Los Angeles, Calif.
Smith, Walter W. Jr., (D), 2144½ Las Colinas Ave., Los Angeles, Calif.
Stevenson, Francis H. (C), 571 South St., Glendale, Calif.
Streeter, Roy E. (D), 4231 Fernwood Ave., Lynwood, Calif.
Tullis, H. T. (C), 1101 E. Anahein, Long Beach, Calif.

MARYLAND

Beck, W. A. (B), Linde Air Products Co., 532 E. 25th St., Baltimore, Md.

MONTANA

Biegel, Milton A. (C), 605 Cheyenne St., Fort Peck, Mont.
Eaton, Clayton L. (D), 4507-Apt. A, Fort Peck, Mont.
Harrison, James R. (D), 4512-B, Fort Peck, Mont.
Mathieson, George E. (D), Apt. 4406-C, Fort Peck, Mont.
Reed, James W. (D), P. O. Box 712, Glasgow, Mont.

NEW YORK

Britten, Clarence R. (B), 555 Mitchell St., Orange, N. J.
Butkis, Albert (D), 660 East 242nd St., Bronx, N. Y.
Ruckel, A. M. (C), American Welding Co., 30 Church St., New York City.
Rudolph, Frederic C. (C), 135 W. 16th St., New York City.
Welker, Ted (D), 103 Wall St., Belvidere, N. J.

WESTERN NEW YORK

Dorrenbacher, John (D), 33 Watkins Ave., Perry, N. Y.
Speller, Thomas H. (C), General Welding & Engrg. Co., 1338 West Ave., Buffalo, N. Y.

OKLAHOMA CITY

Hampton, J. H. (D), 3817 No. McKinley, Oklahoma City, Okla.
Shultz, Bennie (C), Univ. of Okla., c/o Faculty Exchange, Norman, Okla.
Stroup, W. M. (D), 1112 N. W. 50th St., Oklahoma City, Okla.

PHILADELPHIA

Dougel, Harry (C), 626 Du Pont St., Chester, Pa.
Morris, Edward D. (B), Brierhurst Hotel, 4527 Walnut St., Philadelphia, Pa.

PITTSBURGH

McFarland, James R. (D), 8th Street, Warwood, W. Va.
Metzger, William F. (C), P. O. Box 245, New Brighton, Pa.
Roberts, Charles (C), 5700 Penn Ave., Pittsburgh, Pa.

ROCHESTER

Chauncey, Clarence (D), 59 Clayton St., Rochester, N. Y.
Clark, Warren S. (D), 1400 Long Pond Rd., Rochester, N. Y.
Flad, William L. (C), B. & L. Opt. Co., 635 St. Paul St., Rochester, N. Y.
Grant, R. (C), B. & L. Opt. Co., 635 St. Paul St., Rochester, N. Y.
Larson, Ivan E. (C), 639 Avenue D, Rochester, N. Y.
Schwarz, O. G. (B), 87 Harwick Road, Rochester, N. Y.
Schwartz, Harry (D), 1821 Stone Road, Rochester, N. Y.
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NEW PRODUCTS

The Society assumes no responsibility for the validity of claims in this Section

ELECTRIC ARC SAW

An electric arc saw that will cut iron, steel, any alloy metal, ferrous or non-ferrous, Tungsten carbide as readily as low carbon steel, and yet leave the surface of the cut clean and smooth is announced by Miller Electric Mfg. Co., Appleton, Wisconsin, under the trade name "Miller-Strobel" Electric Arc Saw. It is easy and safe to operate, due to the low voltage applied across the arc, and can be operated by any one without special training. It cuts with equal efficiency, economy and speed regardless of the hardness or analysis

of the metal, and without changing the temper or destroying the structure of the metal. It is said to be more economical and faster than any other type of metal cutting.

While the illustration here shows cross cutting, it can be furnished in special models for slotting, turning, arc threading, arc milling and arc turning, etc. Mechanically the sawing unit itself consists of a soft alloy steel blade provided with a multitude of small straight teeth on its circumference. This blade is V-belt driven at a high speed by an industrial type electric motor.

THREE NEW WELDING ELECTRODES

Three new arc welding electrodes, each protected by a heavy extruded coating, have been announced by General Electric's Industrial Department. These electrodes are designed to produce welds to meet Paragraphs U-68 and U-69 of the American Society of Mechanical Engineers' Boiler Code.

Type W-20E is especially designed for general-purpose, single- or multiple-pass arc welding of mild steel in any position. It is particularly suitable for high-speed, single-pass welding and for jobs where fit-up is likely to be poor.

Type W-22E is designed for high-quality, single- or multiple-pass arc welding of steel in any position. This is a fast-melting, smooth-flowing electrode and with it dense deposits can be made without slag inclusions or gas pockets.

Type W-23E is designed primarily for high-quality arc welding of mild steel in the flat position. This is a high-current, or "hot" rod, so that the weld-metal is quite fluid and washes up well on the side walls of deep-groove joints and fillets. Single- or multiple-pass beads can be made at high speeds without slag inclusions or gas pockets.

VERTICAL WELDER

The Harnischfeger Corporation of Milwaukee announces a new machine—the 150 ampere vertical type welder. Designed to occupy a minimum of floor space, this new welder is a highly adaptable machine, available for a wide range of work in welding the lighter gage metals, both ferrous and non-ferrous. With plug-in type cable receptacles for easy current reversing, and patented, single-current control, it sets a new high point in simplicity of welder operation.

HARD-FACING ELECTRODES

The J. D. Adams Company, Indianapolis, Indiana, has brought out two new hard-facing electrodes for use with Arc or Oxyacetylene Process. HFA is recommended for applications where the impact on the abrasive material would cause other hard-surfacing materials to fail. HFB is recommended for all applications where maximum abrasion resistance is desired and where the surface will not be subjected to severe mechanical shock.

NEW ELECTRODE

A new electrode has just been put out by the Page Steel and Wire Division of the American Chain and Cable Co., Monessen, Pa., for flat and position fillet and general flat welding. Booklet available on request.

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-263. Young engineer desires position. Graduated from University of California, 1935. Took Graduate work in Welding Research. Can speak Spanish. Now in New York City. Will go anywhere. Have served as maintenance mechanic, draftsman-engineer; 9 months as electric welder in shipbuilding corporation. Passed first-class navy test for welders.

A-264. Welder desires position. Six years' experience as combination welder. Most of this time spent in shop work, but has worked at production work, pipe line work, industrial piping and had considerable experience at hard surfacing. Would go anywhere if guaranteed a position.

A-265. Welder. Five years' experience as Electric and Acetylene Welder.

A-266. Designing Engineer—Welding design on structural and mechanical engineering. Design of welded buildings, machine bases, cranes and conveyor ovens, two years. Research engineer, asbestos-cement products and asphalt building materials; Control engineer, factory control and inspection, time study and development of production methods for new products, six years. S. B. Civil Eng., M.I.T. '30. Age 30.

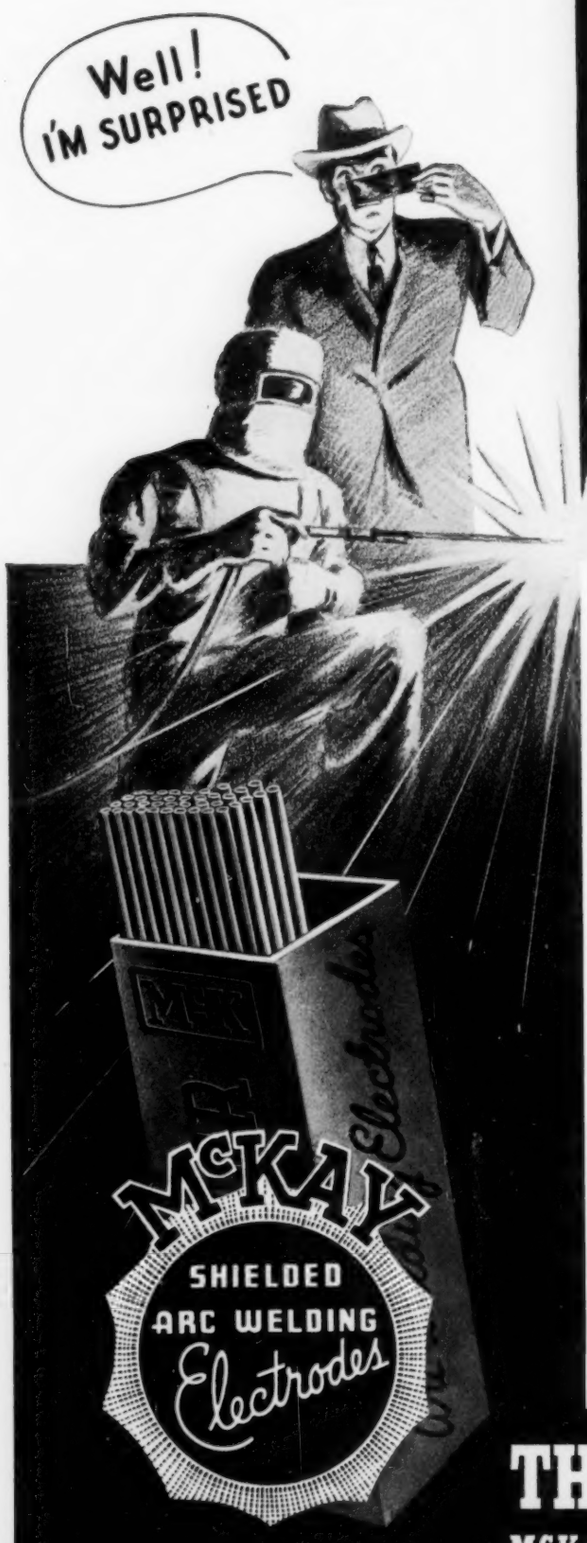
A-267. "Welding rod manufacturing superintendent with an outstanding record of accomplishment in the production of all types of arc-welding rods desires to make a change. Experienced in rod development as well as production."

POSITIONS VACANT

V-86. Wanted—To act as ad distributor for well known manufacturer of welding rod by old established wholesalers of plumbing and heating materials in Paterson, N. J., and vicinity. Have sales outlets—both manufacturers and dealers—guaranteed.

Yes!

McKAY ELECTRODES will give you BETTER PERFORMANCE



A McKay electrode was lately tested in a user's own shop against three other rods, each considered best for one particular requirement. To the surprise of the shop men, this McKay rod gave an improved demonstration in all three uses. Faster, quieter, making less spatter and laying a bead of superior appearance, the one electrode outdid all the other three very definitely, and of course procedure was simplified. McKay Shielded-Arc Welding Electrodes will speed your work and improve your finished job. A folder, giving necessary data, will be mailed on request.

THE McKAY COMPANY

McKAY BUILDING PITTSBURGH, PA.

THE ENGINEERING FOUNDATION
Welding Research Committee
and American Institute of Electrical Engineers
Sponsored by the American Welding Society

Supplement to the Journal of the American Welding Society, June 1938

ARC WELDING ATMOSPHERES*

By GILBERT E. DOAN† and ARDREY M. BOUNDS‡

THE inert gases, particularly the more abundant ones such as argon, helium and neon, can be used to simplify the arc welding process by conducting the welding in these gases, thus eliminating the chemical reactions of the air. The use of pure iron electrodes and base plates, instead of steel with all its impurities, permits the fundamental nature of the welding processes to come still more clearly into view. Earlier reports[1,2,3,4] of pure iron welds in argon have shown that (*a*) with drastically purified inert gases and pure metal electrodes much higher voltages are necessary to produce stable arcs, whereas with slightly impure gases a stable arc forms readily. (*b*) Under the welding arc in these gases there is no crater formation whatever. (*c*) The globules on the end of the electrode grow to a very large size before they drop off, the "Pinch effect" seeming to be inoperative. (*d*) The ductility of these pure iron welds is very high, their strength low. They do not age harden.

Recently welding experiments in argon were made with very high currents in an attempt to get penetration in spite of the absence of crater formation noted above. Ordinary steel electrodes were used for comparison with the pure iron reference values reported previously. The welding chamber and the automatic feeding devices are fully described in the papers cited above. A general view is given in Fig. 1. Although previous experiments with currents of ordinary magnitudes in argon gave no fusion of the plate whatever, good fusion of the base plates was obtained with these high currents, as shown in Fig. 2. The plates were $^1/_4$ inch thick, of ordinary low-carbon steel. The wire was commercial low-carbon steel (C = 0.05, Mn 0.11, P 0.006, S 0.021, Si 0.02, N_2 0.003, O_2 0.012, H_2 0.004). Welding current of 240–250 amperes with a 22-volt arc was used. The open circuit voltage was 135. Current for these welds had to be drawn from a large constant potential generator instead of from the low-voltage arc welding generator commonly used.

Welds made with lower currents, 140, 160, 180 and 195 amperes, had insufficient fusion. One of the necessary conditions for welding steel in inert gases would thus seem to be an abnormally high current and an electrode size capable of carrying this high current.

* Contribution to Fundamental Research Division, Welding Research Committee.

† Professor, Dept. of Metallurgical Engineering, Lehigh University.

‡ Engineering Foundation Research Fellow at Lehigh University.

1. "Arcs in Inert Gases—I, II and III," *The Physical Review*, April 1, 1932, July 1, 1934, May 15, 1935.
2. "Researches in Arc Welding," *Electrical Engineering*, Sept. 1932.
3. "Arc Welding in Argon Gas," *Electrical Engineering*, Nov. 1935.
4. "The Metallurgy of Pure Iron Welds," *Metals Technology*, Feb. 1936.

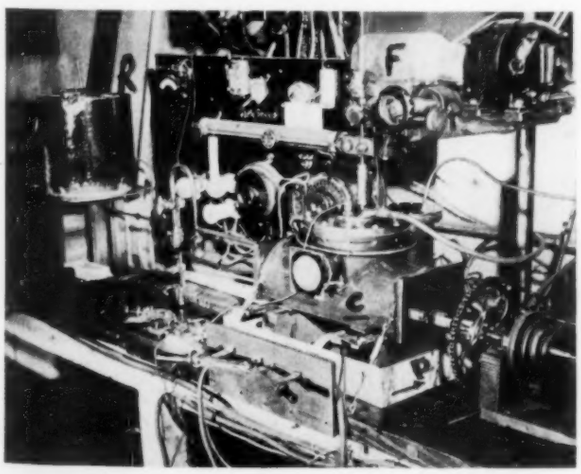


Fig. 1—Experimental Welding Apparatus. *C* — Welding Chamber; *R* — Gas Reservoir to Prevent Rise in Pressure in Chamber; *F* — Automatic Electrode Feed; *P* — Automatic Plate Feed

Fig. 2—Showing Fusion of $^1/_4$-Inch Plates in Argon Using Steel Electrode, 250 Amperes

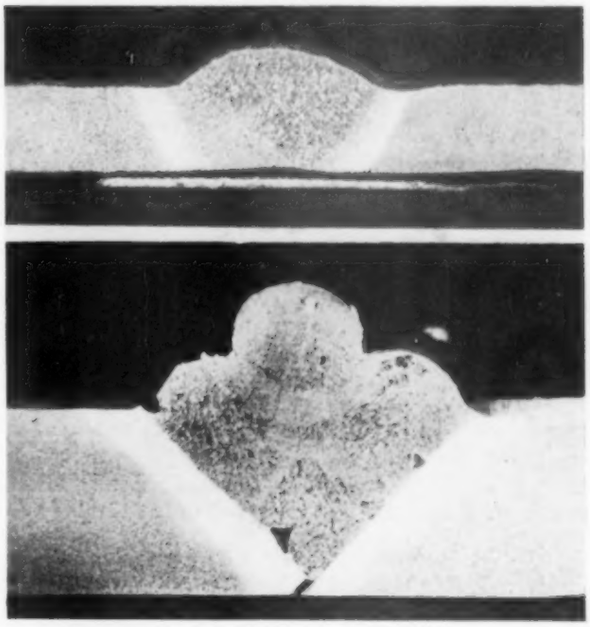
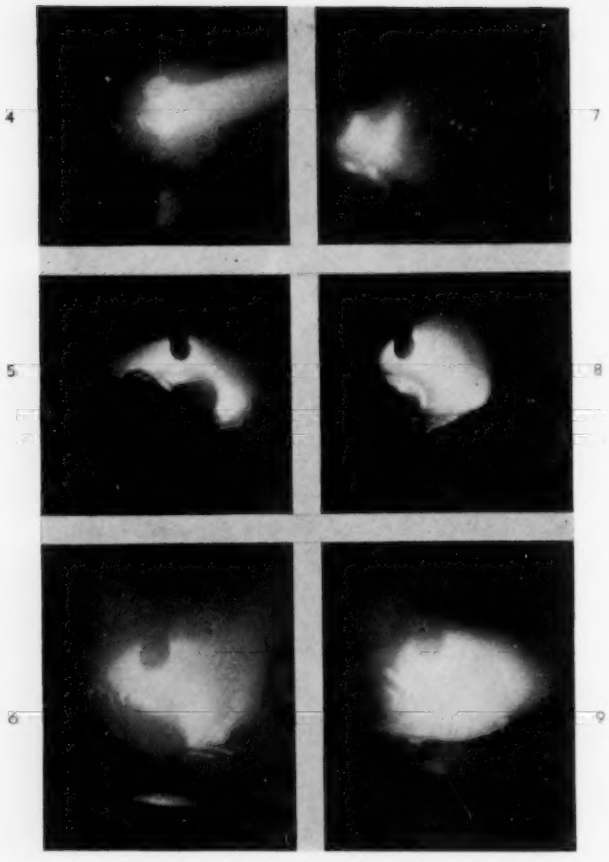


Fig. 3—Steel Weld in Argon on $^1/_2$-Inch Steel Plates, Lower Currents Than in Fig. 2. Note Lack of Fusion Into Plates, Good Fusion Into Heads



Figs. 4 to 9—Series of Arcs in Argon

When the lower currents were used, very little fusion into the plates could be found, as is shown in Fig. 3, showing a 90° V in $^1/_2$-inch plates. But strangely enough good fusion could always be obtained into the previous beads of weld-metal. This is also shown in Fig. 3. The arc voltage was 32, which indicates a rather long arc. When reduced to 15 volts to get a shorter arc and deeper penetration, even less penetration resulted, due apparently to the fact that the drops formed on the electrode bridged the arc gap before they had become sufficiently superheated and before the plate beneath them had formed a molten pool to receive them. The range of arc length from 15 to 32 volts was explored with the result that 20 to 22 volts was finally determined to be the optimum value (135 volts open circuit). This voltage left about $^1/_8$ inch between the fully grown globule and the plate when the drop fell. Arc voltages above this value produce an unusually large amount of iron vapor, and penetration is again decreased rather than increased. With long arcs the magnetic blow becomes very violent, the drop swirling about rapidly on the end of the electrode and often swinging off to one side instead of falling into the groove. Figures 4 to 9 show a series of arcs in argon. Reversed polarity (positive electrode) gave even less penetration than straight polarity.

POROSITY OF STEEL WELDS IN ARGON

Although the plate fusion obtained with high currents is quite satisfactory, the weld itself is porous, containing so many large blow-holes that a tension test made from it would be meaningless. This porosity is not evident in Fig. 2, but prevailed throughout other parts of the specimen. Strangely, *pure iron* welds in argon do not exhibit this troublesome porosity, as shown in Fig. 10, which is a pure iron weld on steel plates in argon gas. The usual absence of penetration with ordinary welding currents is evident, but the weld-metal is sound. Figures 11 and 12 show steel globules in argon before and after sectioning. The porous sections revealed by the two large globules indicate, but do not fully prove, that the gases which cause the porosity come from the steel itself. They may, on the contrary, be caused by argon dissolved in the steel globule coming out of solution on cooling. Figures 13 and 14 show for comparison a single globule of pure iron in argon before and after sectioning. All such globules examined were free from porosity. The exterior of a multi-layer steel weld in argon is shown in Fig. 15. The surface of welds in argon is that of bright silver with no dullness or tarnish whatever, and of course no slag or oxide film.

CRATER FORMATION

No true crater formation has been observed in any weld in argon, even with the very high currents used. One

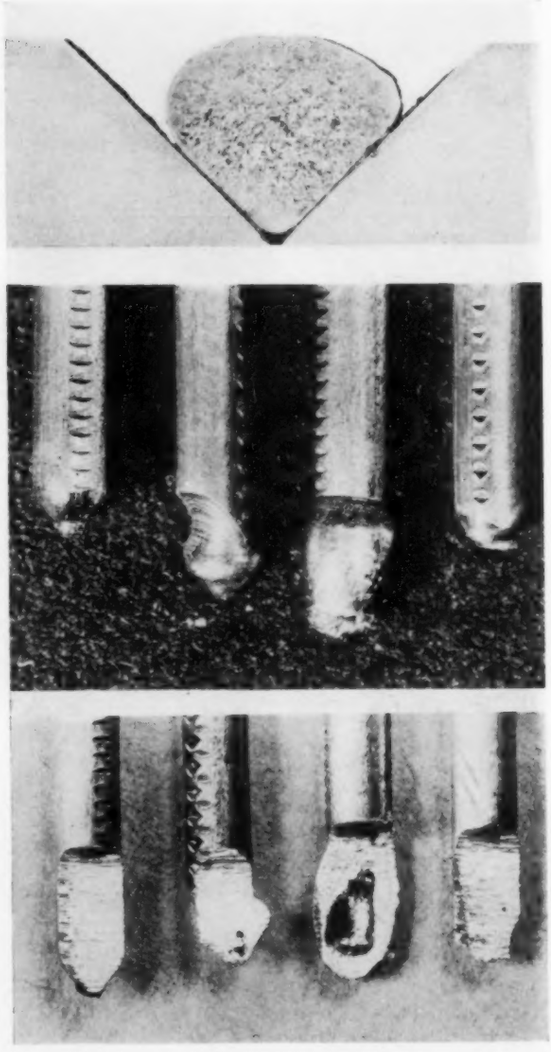


Fig. 10—Pure Iron on Steel Plate in Argon. Note Absence of Penetration and of Porosity
Fig. 11—Steel Globules After Welding in Argon Before Sectioning
Fig. 12—Steel Globules After Welding in Argon After Sectioning. Note Cavities

may observe clearly the melting of the plate into a small liquid pool under the arc but this pool never shows the slightest depression, and only occasionally a few ripples. The same absence of crater was found also in CO gas, in mixtures of nitrogen and hydrogen, and in city gas, as reported below.

In hydrogen welding (described below) no crater was observed until the current was raised to 200 amperes (wire diameter $^1/_8$ inch) and then only a very slight depression was observable, as shown in Fig. 16. For comparison, the crater obtained in ordinary air welding is shown in Fig. 16*a*. These results do not agree with those obtained by investigators who welded in *flames* of hydrogen and carbon monoxide, possibly because welding in a closed chamber such as ours prevents the admixture of air in the welding atmosphere being used, whereas shooting a jet of gas at the arc in the open air can give no such rigid control.

Fig. 13—Pure Iron Globule After Welding in Argon, Before Sectioning

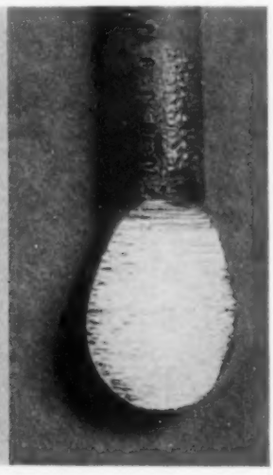


Fig. 14—Pure Iron Globule After Welding in Argon, After Sectioning. Note Absence of Porosity

STEEL AND PURE IRON WELDS IN HYDROGEN

Because of the impracticability of using the inert gases for commercial welding, cheaper gases were tried as substitutes. In hydrogen of commercial purity, the shortest arc obtainable showed a voltage drop of 32 volts. With open circuit voltage up to 90 the arc in hydrogen is quite unstable, but with 120 volts a perfectly stable arc could be maintained. The following analyses of the gas in the chamber before and after welding indicate that there was little, if any, leakage into the chamber, since the analyses agree within the limit of error of the Haldane gas apparatus which was used.

	Before Welding, %	After Welding, %
CO_2	0.2	0.2
O_2	0.2	0.3
N_2	1.8	1.7
H_2	97.8	97.8

Steel welds with the $^1/_8$-inch diameter wire used in all these experiments showed no true crater formation in the molten deposit but considerable fusion into the plate, as shown by Figs. 17 and 18.

Apparently a crater was formed momentarily when the arc was first struck, but as soon as any deposition of metal took place the arc went to the deposited metal rather than to the plate and the bead continued to be built up by large drops quietly falling. If the arc was broken and the parent metal moved along so that the electrode would strike the plate again, a crater was formed until sufficient deposit was accumulated.

All of the welds were extremely porous, as the photo shows. Arc voltages from 32 to 45 volts were used and currents up to 150 amperes. At currents above 120 amperes the melting rate of the wire became so fast that the feeding apparatus could not keep up with the melting and the arc would go out due to lengthening. The electrode deposited in large drops as in argon. The arc is accompanied by a metallic ringing sound but no crackle.

During welding a layer of powder $^1/_{16}$-inch deep formed in the chamber. In the case of argon welds, X-ray analysis showed this powder to be alpha iron. No analysis of the powder formed in hydrogen was made, although it was especially copious.

Pure iron was next tried in hydrogen. The results were rather surprising. Pure iron when deposited in argon fuses quietly and drops to the plate beneath, forming a continuous solid bead. When deposited in hydrogen, it absorbs far more gas than steel does and continues to bubble and blow for some seconds after deposition. The result is the mere shell of a bead, as shown in Fig. 20 where a deposit of pure iron on pure iron plate is pictured. After the bead has begun to freeze, the bubbles of hydrogen burst from the surface and a marked recalescence of the metal takes place. If hydrogen has a negative heat of solution in iron, this recalescence may be from the heat of solution given up when the hydrogen escapes. On the other hand, it may be merely the mechanical effect of bringing up hotter liquid metal from the interior of the bead. The same phenomenon was observed with steel electrodes in hydrogen.

There is such a marked difference in the solubility of hydrogen in pure iron and in steel that the small amounts of C, Mn and Si found in the wire must have a very large effect.

HYDROGEN-NITROGEN MIXTURE

A 75% hydrogen, 25% nitrogen mixture, simulating cracked ammonia, was used next. The results were the

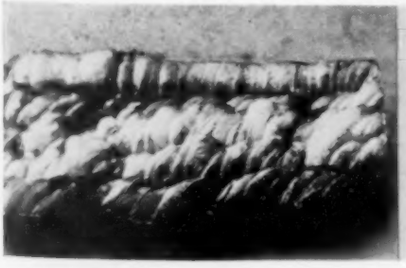


Fig. 15—Steel Weld in Argon. Note Silvery Surface Appearance and Good Fusion of Beads

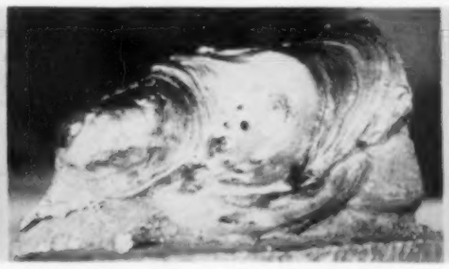


Fig. 16—Steel Weld in Hydrogen 250 Amperes. Note Semblance of a Crater in Center, Gas Bubble at Left

Fig. 16*a*—Crater Formation in Ordinary Air Welding

Fig. 17—Steel Weld in Hydrogen, Open Circuit Voltage 120, Arc Voltage 32-48, Current 120 Amperes. Note Porosity and Fusion Into Plate

Fig. 19—Section of Steel Weld in Hydrogen at Lower Current

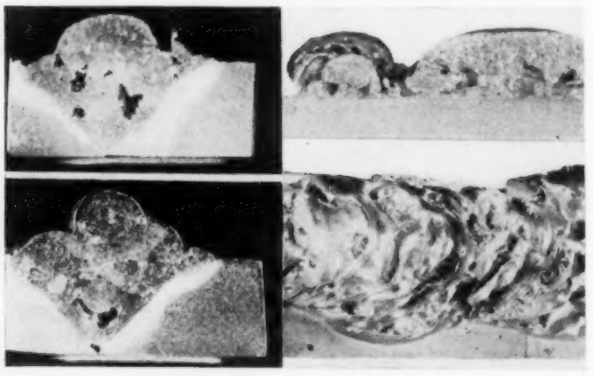


Fig. 18—Another Steel Weld in Hydrogen

Fig. 20—Pure Iron Deposited on Pure Iron Plate in Hydrogen. Note Porosity. (Plan View)

same as those obtained when welding in pure hydrogen, namely great porosity, lack of penetration, and of course, lack of crater formation. The best electrical conditions used were 90 volts open circuit, 38 volts at arc, 125 amperes in $^1/_8$-inch wire.

	Gas Before Welding, %			
Run No. 1—CO_2	0.4	Run No. 2—CO_2	0.3
O_2	0.8	O_2	0.6
N_2	24.3	N_2	23.7
H_2	74.5	H_2	74.5
	Gas After Welding, %		
Run No. 1—CO_2	0.1	Run No. 2—CO_2	0.8
O_2	0.4	O_2	0.6
N_2	22.2	N_2	21.8
H_2	77.8	H_2	76.8

Unfortunately no microscopic or age hardening studies were made on this weld. If the theory of nitrogen absorption advanced by several investigators be true, no nitrogen needles should be found in this metal. This theory postulates that the nitrogen is fixed from oxides of nitrogen produced in the arc and that the uncombined gas is not appreciably soluble. On the contrary, ionization and dissociation of nitrogen in the arc may render it quite active chemically.

ILLUMINATING GAS

Welds made in illuminating gas give absolutely no indication of crater formation. The surface appearance of the bead is similar to that of beads formed in inert gas welding. A copious deposit of soot forms in the chamber. The welds absorb carbon and can be cut only with a high speed saw and at that only with difficulty. The metal is 34 to 35 in hardness on the Rockwell C scale. It is fairly sound but quite brittle.

Analysis of the gas before and after welding (courtesy of the Bethlehem Steel Co.) gives:

Original Gas, %		After Welding, %
CO_2	2.6	1.1
Illuminants	2.7	1.9
O_2	0.3	.8
CO	6.1	6.8
CH_4	28.3	10.7
H_2	42.4	59.6
N_2	17.6	19.1

Apparently the CH_4 breaks down extensively and supplies a good deal of the soot. The CO does not seem to break down, and this looks promising as an arc atmosphere. The experiments are not yet complete.

WELDING IN CO

No crater formation was observed during welding in carbon monoxide but adequate penetration by simple fusion was obtainable with 120 amperes, 22 volts (75 volts open circuit). The welds were quite porous and they "blew out" gas every time the arc was stopped for any readjustment. These experiments are not yet completed.

SUMMARY

Steel welds in argon are almost invariably porous. Thus, it has not been possible to find what a "perfect" shielding of the commercial steel arc from the action of air would give in the way of physical properties, although this result has been found previously for pure iron. While crater formation is absent, penetration by simple fusion can be obtained by the use of currents of the order of 200 to 250 amperes in a $^1/_8$-inch wire and on $^1/_4$-inch thick plates. An open circuit voltage of 135 is necessary for obtaining a stable arc.

True crater formation was not found in any of the gases used, although hydrogen showed some tendency in this direction. All of the steel welds made in hydrogen and in the mixture of hydrogen and nitrogen were porous to the degree that tension tests would be meaningless. The same is true of the pure iron welds made in hydrogen.

Welds made in illuminating gas are fairly sound but very hard and brittle.

The preliminary welds made in CO gas are porous.

ACKNOWLEDGMENTS

The Engineering Foundation provided the funds which made these studies possible. The General Electric Company contributed the automatic welding bead. The Lincoln Electric Company provided the welding generator. Mr. William C. Schulte, of the Lukens Steel Company, former Engineering Foundation Research Fellow, generously assisted in the conduct of the program. The Bethlehem Steel Company assisted in the gas analyses.

TRANSLATION

A few copies of an extended abstract of a paper entitled "The New Specifications for German High Tensile Structural Steel (St 52), Resulting from Research and Experience," by DR. KOMMERELL (Director of German State Railways) have been made available by Jonathan Jones, Chairman Subcommittee F, Fatigue Testing (Structural) of the Industrial Research Division of the Welding Research Committee. The original article was published in *Stahlbau*, April 8, 1938. Besides discussing methods of patching cracked welds in high tensile steel, Dr. Kommerell reports results with a new type of bend test in which a bead of weld-metal is deposited on the tension side of a bend test specimen.

WELDED BEAM-COLUMN Connections*

By T. A. WEYHER†

SYNOPSIS

THE object of this paper is to develop rational design formulas for welded beam-column connections. Rigid connections only are considered. Three different sizes of joints, each providing a different degree of end restraint, are suggested.

INTRODUCTION

Early methods of design of welded beam-column connections envisaged flexible connections. The theory of design was based on providing resistance to shear only. One method used only web welds and no flange welds. In 1930, investigators Uhler and Jensen found that this type of joint was badly overstressed. Other suggested methods of connection involved the use of composite joints of welds and rivets with gusset plates. One of the latest methods described uses angle connections between top and bottom flanges and the column. The methods proposed in this paper contemplate the use of flange and web welds with or without one or two gusset plates, depending on the degree of end restraint desired.

THEORETICAL CONSIDERATIONS

Allowable Unit Stresses in Weld-Metal.—Present American practice indicates that the following design stresses for low-carbon steel welds should not be exceeded:

Tension	13,000 lb./sq. in.
Compression	15,000 lb./sq. in.
Shear	11,300 lb./sq. in.
Flexure	as for tension or compression.

* Abstracted from a thesis submitted to M.I.T. Contribution to Fundamental Research Division, Welding Research Committee.

† Captain Ordnance Department, U. S. Army.

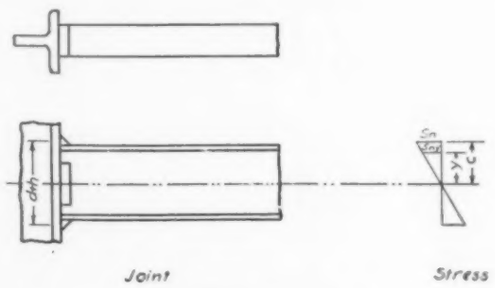


Fig. 1—Small Connection

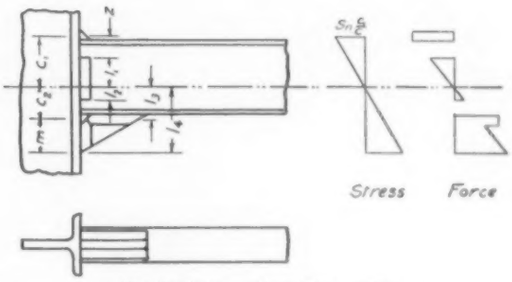


Fig. 2—Intermediate Connection

Stress concentrations at the neck and root of fillet welds are not provided for in the design. Due to plastic flow these are believed to disappear beyond the local elastic limit. They have not had any effect on the ultimate strength of the welds. Failure in fillet welds transverse to the applied force is generally across the throat. This is in spite of the reinforcement that is inevitable in laying down the weld.

Let P equal the force applied normal to one leg, h, of a unit length of a 45 degree weld. The unit stress produced by this force on the throat of the weld has been given variously as follows:

$$(a)\quad s = \frac{1.414\,P}{h}$$

$$(b)\quad s = \frac{2\,P}{h}$$

$$(c)\quad s = \frac{1.618\,P}{h}$$

The last represents the principal stress at the throat. It is best supported by tests.[1] It will form the basis of the formulas developed in this paper. (See also Appendix I.)

Connection Angles.—The use of connection angles except for erection purposes is condemned. They introduce elements of end restraint whose magnitude defy easy and sure determination. They serve no useful purpose that cannot be better served by the use of flat plates. The methods of making the three connections considered herein are shown diagrammatically by Figs. 1, 2 and 3. They will subsequently be referred to as the small, intermediate and large moment connections, respectively.

DERIVATION OF FORMULAS

Notation.—The symbols used in this paper conform as far as possible to those compiled by the American Standards Association.

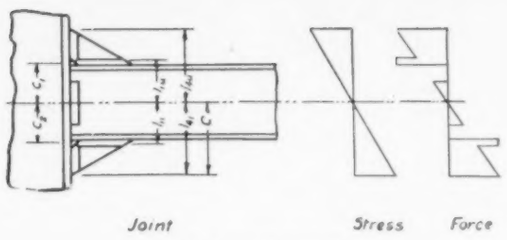


Fig. 3—Large Connection

d = depth of beam, in.
n = length of web weld, one side, in.
m = length of gusset column weld, one side, in.
h = length one leg of fillet weld, in.
h_f, h_w = length of leg of fillet weld on flange and web respectively, in.
S = total vertical shear at column, lb.
s_n = stress normal to throat section of weld, lb./sq. in.
s_t = principal stress on weld throat, lb./sq. in.
s_z = allowable stress in tension, rolled section, lb./-sq. in.
P = force acting on weld, lb.
P_m = force acting normal to vertical side of gusset, lb.
M_{r_1} = resisting moment flange welds, in. lb.
M_{r_2} = resisting moment web and gusset welds, in. lb.
M_r = resisting moment of connection, in. lb.
c = distance neutral axis to extreme fiber, in.
c_1, c_2 = distance neutral axis to top and bottom flange welds, respectively, in.
c_f, c_g, c_w = distance neutral axis to center of gravity of a flange, vertical leg of a gusset, and that portion of the web in compression, in., respectively.
y = distance neutral axis to any point on joint, in.
l_1, l_2, l_3, l_4, l_5, l_6 = distance neutral axis to the top of the web weld, bottom web weld, bottom upper gusset weld, top upper gusset weld, top lower gusset weld, and the bottom lower gusset weld, respectively, in.
t_s, t_w, t_g = thickness gusset stiffener, beam web and gusset plate, respectively, in.
b = breadth of beam, in.
b_s = breadth of gusset stiffener, in.
z = distance between end of web weld and outer surface of flange, in.

1. Size of Weld Fillet.—In the formulas developed, the welds are made no stronger than the plates they connect. Assume a strip of web of unit depth (Fig. 4). Then $\frac{2P}{t} = s_z$. But $s_t = \frac{1.6P}{h}$, whence $h = \frac{0.8\ s_z\ t}{s_t}$ for welds on both sides of the web. For flange welds, which are on one side only, h is double this amount.

2. Fundamental Derivation of the Unit Stresses.—(See also Appendix I.)

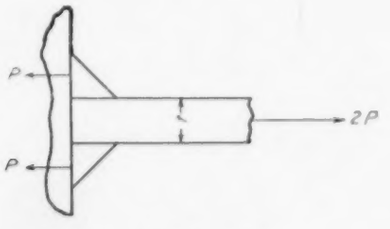


Fig. 4—Size of Weld

$$dP_n = dP_s = dP \cos 45° \qquad \text{Fig. 5.}$$

$$s_n = s_s = \frac{dP \cos 45°}{h\,dy \cos 45°} = \frac{dP}{h\,dy}$$

$$s_t = \frac{s}{2}\ s_n + \sqrt{s_s^2 + \frac{s_n^2}{4}} = 1.618\ s_n$$

3. Design of the Small Moment Connection.—In all that follows Hooke's law is assumed to hold below the elastic limit. The small moment connection is made by a fillet weld on each side of the web and one on both the top and bottom flanges. The resisting moment of the flange welds, M_{r1}, is $P_1c_1 + P_2c_2$.

$$P_1 = \frac{s_t\ bh\ c_1}{1.618c} \text{ and } P_2 = \frac{s_t\ bh\ c_2}{1.618c}, \text{ whence}$$

$$M_{r1} = \frac{s_t\ b\ h_f}{1.618c}(c_1^2 + c_2^2) \qquad (1)$$

The resisting moment of the web welds, $M_{r2} = 2\int y\ dP$ integrated between proper limits.

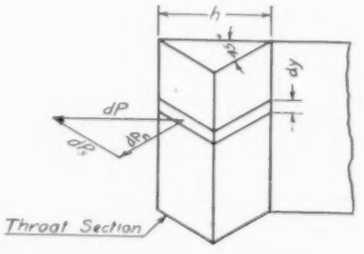


Fig. 5—Section of Fillet Weld

$$dP = s_n\ y\ h\ dy = s_t\ \frac{y\ h\ dy}{1.618\ c}, \text{ whence}$$

$$M_{r2} = \frac{s_t\ h_w}{2.43c}\ (l_1^3 + l_2^3) \qquad (2)$$

The resisting moment of each component of the cross section of the joint in compression must also be determined from a consideration of the method of assembly. If the beam fits snugly against the column, it will be simpler to determine the resisting moment of the flange and the web separately, as follows:

$$M_{rf} = \frac{A_f c_f^2 s_n}{c}, \text{ and } M_{rw} = \frac{A_w c_w s_n}{c} \qquad (3)$$

$$\text{If plates are used, then } M_{rp} = \frac{A_p c_p^2 s_n}{c} \qquad (4)$$

where A is the cross-sectional area of the component.

4. Design of Intermediate and Large Moment Connections.—These two connections are designed in exactly the same manner as the small moment connection. The formula for the resisting moment of the flange weld is the same. In the formula for the resisting moment of the web welds, additional terms are necessitated by the presence of the gussets.

For the intermediate moment connection,

$$M_{r3} = \frac{s_t\ h_w}{2.43c}\ (l_1^3 + l_2^3 - l_3^3 + l_4^3)$$

For the large connection

$$M_{r4} = \frac{s_t\ h_w}{2.43c}\ (l_1^3 + l_2^3 - l_3^3 + l_4^3 - l_5^3 + l_6^3)$$

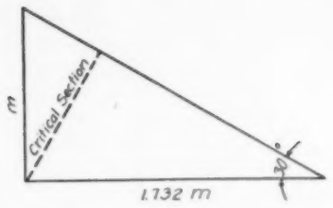


Fig. 6—Proportions of Gussets

Compression on the cross section must be considered as in the small connection. The addition of compression on a gusset requires another term, M_{re}, which equals

$$\frac{A_e c_e^2 s_n}{c}.$$

5. *Finding the Neutral Axis.*—The neutral axis is found by equating the total compression to the total tension. The stress in the connection is assumed to vary as the distance of a given point from the neutral axis. It is convenient to break down the connection into its component parts, compute the force acting on the various parts in terms of c, combine all the forces thus found, and solve for c. The method is illustrated in the problem which follows.

6. *Design of the Gussets.*—The gussets used are 30°–60° gussets with the short side against the column. The critical section is the normal to the hypotenuse. (Fig. 6.) The critical fiber is at the point r. At this point the shear is zero and the principal stress is normal to the section. As a simplifying assumption, on the side of safety, the vertical shear at the column is taken as uniformly distributed over the web and gusset welds. The various forces acting on the assumed free body are shown in Fig. 7. Further, $g = \dfrac{\bar{x} \sin \alpha}{\sin (150 - \alpha)}$ in which

$$\alpha = \tan^{-1} \frac{P_m (m + n)}{m S}$$

$$P_m = \frac{2 s_n h_g}{c} \int_{l_3}^{l_4} y \, dy = \frac{s_n h_g}{c} (l_4^2 - l_3^2) \text{ and}$$

$$\bar{x} = \frac{(2l_4 + l_3)m}{3(l_4 + l_3)} \text{ (center of gravity of trazoid).}$$

$$e = g - 0.433 m$$

$s_e = \dfrac{Mc}{I} \pm \dfrac{P}{A}$ for eccentric loading of the critical section.

From the above relationship, it will be found that

$$s_e = \frac{1.732 \, s_n h (l_4^2 - l_3^2)(m + n) + cmS}{2 \, cmt(m + n)} \left[\frac{8(2l_4 + l_3) \sin \alpha}{3(l_4 + l_3) \sin (150 - \alpha)} - 2.31 \right]$$

A column formula of the form $\dfrac{P}{A} = 16{,}000 - c \dfrac{l}{r}$ will now be applied to a small strip along the outside edge of the gusset[15] for the compression side gusset. As the strip is held along its inner edge and is restrained at the ends, the usual value of c of 70 for pin ended columns may be reduced. 40 seems reasonable under the circumstances. Then,

$$s_e = 16{,}000 - \frac{80 \, m}{t} \text{ whence,}$$

$$t = \frac{s_n h (l_4^2 - l_3^2)(m + n) + cmS}{30{,}000 \, cm(m + n)} \left[\frac{8(2l_4 + l_3) \sin \alpha}{3(l_4 + l_3) \sin (150 - \alpha)} - 2.31 \right] + 0.005m$$

For tension side gussets, omit the last term.

The foregoing derivation is for simple flat plates for gussets. If it is found expedient to use lighter plates than the formula indicates, the same principles and reasoning can readily be extended to gussets with T sections. The equations are so involved when an explicit function of t is sought that a trial and error solution seems to be the best approach. When b_e is less than one twelfth the hypotenuse of the gusset, a compressive stress of 16,000 lb./sq. in. may be used. When b_e is greater than this value, the stress should not exceed,

$$s_c = 19{,}000 - \frac{500 \, m}{b_e}$$

7. *Illustrative Example.*—(Figure 8.)

6-in. I beam, 14.75 lb./ft.
Area beam flange 1.57 sq. in.
Thickness of web 0.3 in.
Distance center of gravity of flange from outer edge = 0.3 in.
Flange depth = 0.95 in.
b = 3.00 sq. in.
h = 0.22 in.
z = 1.33 in.
m = 2.90 in.
n = 3.40 in.
d = 6.06 in.
t_w = 0.25 in.

Problem: To find the resisting moment of this intermediate connection.

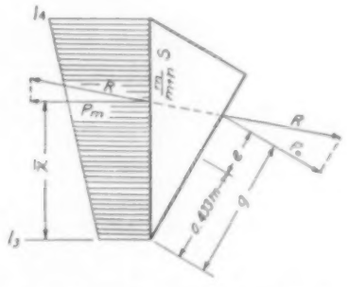


Fig. 7—Forces on Gusset Critical Section

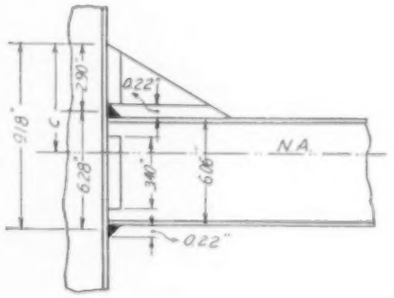


Fig. 8—Illustrative Problems

Solution: Find the neutral axis first. Expressions for the forces in compression and in tension are set up. For the flange welds, the force, $P = \frac{s_n y b h}{c}$; for the gusset and web welds, $dP = \frac{s_n h y\, dy}{c}$; and the unit stress on the beam cross section is $\frac{s_n y}{c}$. In the following tabulation $\frac{s_n}{c}$ is common to all expressions and is omitted.

	c^2		c			
	+	−	+	−	+	−
P bottom fl. weld $= -0.22 \times 3.00\,(9.18 - c)$			0.66		6.07	
P beam fl. $= -1.57(9.18 - c - 0.11 - \frac{0.95}{2})$			1.57		13.50	
P beam web $= -0.3(9.18 - c - 0.11 - 0.95)^2/2$	0.15		2.44		9.85	
P web and gusset $= 0.22 \times [-(9.18 - c - 0.11 - 1.33)^2 + (c - 2.90 - 0.11 - 1.33)^2 + c^2 - (c - 2.90)^2]$			2.77		10.91	
P top fl. $= 0.22(3.00 - 0.25)(c - 2.90)$			0.61		1.76	

$$0.15c^2 - 8.05c + 42.09 = 0$$

$c = 5.93$ in.
$c_1 = 3.25$ in.
$c_2 = 3.03$ in.

The resisting moment of the component parts can now be found.

$$s_n = \frac{13{,}000}{1.618} = 8000$$

$$M_r = \frac{13{,}000 \times 0.22}{2.43 \times 5.93}\,(1.81^3 - 3.03^3 + 1.59^3 + 5.93^3 + 1.5(3.25^2 \times 3.00 + 3.03^2 \times 2.75) = 54{,}700$$

M_r beam fl. $= 1.57 \times 8000 \times \frac{(9.18 - 5.93 - 0.11 - 0.95/2)}{5.93} \times (9.18 - 5.93 - 0.11 - 0.30) = 16{,}080$

M_r beam web $= \frac{0.3 \times 8000 \times 2.30^2}{2 \times 5.93} = 1{,}070$

Total $M_r = \overline{71{,}850}$ in. lb.

Check the gusset for the maximum stress. Assume the shear as 20,000 lb.

$$\alpha = \tan^{-1}\frac{P_m(m + n)}{mS}$$

$$P_m = \frac{8000 \times 0.22}{5.93}\,(5.93^2 - 3.03^2) = 7730 \text{ lb.}$$

$$\alpha = \tan^{-1}\frac{7730\,(2.90 + 340)}{2.90 \times 20{,}000} = 40°$$

$$s_s = \frac{1.732 \times 8000 \times 0.22\,(5.93^2 - 3.03^2)(2.90 + 3.40) + 5.93 \times 2.90 \times 20{,}000}{2 \times 5.93 \times 2.90 \times 0.25(2.90 + 3.40)} \times \left[\frac{8(2 \times 5.93 \times 2.90)\sin 40}{3(5.93 \times 2.90)\sin 110} - 2.31\right]$$

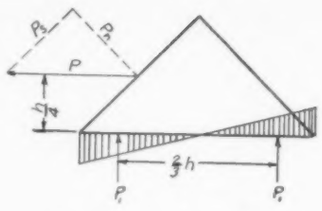


Fig. 9—Forces on Fillet Weld

$s_c = 12{,}100$ lb./sq. in.

Check the welds to see that the parent metal will not fail first.

For the gusset welds, $h = \frac{0.8 \times 16{,}000 \times 0.25}{13{,}000} = 0.24$ in.

Hence, the parent metal will not fail before the welds.

EXPERIMENTAL RESULTS

The writer built up several connections purposely weaker than the beam and tested them to destruction. Each type of connection was represented in the tests. The results are found in Table 1 herewith.

Table 1

Test No.	Type of Connection	Ultimate Applied Load Moment, In. Kips	Ultimate Applied Load Shear, Kips	Computed Strength In. Kips	Factor of Safety
1	Small	300	8.3	64.3	4.7
2	Small	293	8.1	64.2	4.6
3	Large	383	10.7	138.0	2.8
4	Intermediate	448	15.0	96.7	4.6
5	Large	412	13.7	89.6	4.6

The joints tested were fabricated of 6 in. − 14.75 lb. I-beams. The specimens were prepared by welding 42-inch lengths of beam to the opposite flanges of a short vertical 12-inch I-beam. The ends of the 6-inch beams were loaded upward and the center of the 12-inch beam was loaded downward in a beam testing machine. No reason for the premature failure in Test No. 3 can be advanced. None of the joints was stress relieved. Field conditions were simulated as closely as possible.

CONCLUSIONS

The methods developed in this paper are easily applied in the analysis of the connections considered. For actual design a trial and error approach is indicated at present. The connections proposed are simple; the assumptions made accord with facts.

ACKNOWLEDGMENT

Thanks are due to Professors C. E. Fuller and C. W. MacGregor for their suggestions and criticism, to Mr. H. R. Bullock for his help in preparing the specimens, to the Massachusetts Institute of Technology for per-

mission to use material from a thesis submitted by the writer in partial fulfillment of the requirements for the degree of Master of Science, and to the Ordnance Department, U. S. Army for permission to use the thesis.

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APPENDIX I

Analysis of unit stresses in welds.

The critical section of a fillet weld is the throat. Fig. 9.

Let P = the force per lin. in. of weld.

P_1 = resisting force

M = applied moment $= \frac{Ph}{4}$

M_1 = resisting moment $= \frac{2\,P_1 h}{3}$

$M = M_1$

$\frac{Ph}{4} = \frac{2\ P_1 h}{3}$, therefore $P_1 = \frac{P}{8}$

$$\frac{1}{2}\left(s_t \times \frac{h}{2}\right) = P_1 = \frac{P}{8}$$

whence, $s_t = \frac{1.5\,P}{h}$, which represents the maximum fiber along the horizontal leg.

To find the stress on the throat:

$P_s = P_n = P \cos 45°$

$$s_n = \frac{P \cos 45°}{h \cos 45°} = s_s$$

The principal stress, $s_t = \frac{s_n}{2} \pm \sqrt{\frac{s_n^2}{4} + s_s^2}$. Therefore, $s_t = \frac{1.618\ P}{h}$ which is the maximum fiber stress on the throat and is greater than that on the leg.

PROGRESS IN WELDING DURING the Last Six Months of 1937*

By WILHELM LOHMANN

1. MATERIALS

ONE of the most difficult high-alloy steels to weld is 14% manganese steel. In common with other high-alloy steels the welding of 14% manganese steel remains of practical interest because new applications of the steel are constantly arising, as B. H. Payne[1] points out. A rod containing 5% Ni has displaced the plain 14% Mn rod, which is sensitive to cracking. In view of the high coefficient of expansion of austenitic steels, undue heating of the base metal is dangerous since shrinkage stresses and cracking increase with heating. On this account arc welding is preferable to gas. The electrodes should have as thin a coating as possible, or none at all. The electrode is deposited with a slow oscillating motion. Energetic peening of the hot weld-metal is important to release the locked-up stresses. Only half an electrode should be deposited at one spot. Cracks in castings may be burnt out with a torch. To prevent spreading, the ends of the crack should be drilled out, or a hole burnt through.

The weldability of steels with tensile strengths of 70,000 to 85,000 lb./in.^{2} used in shipbuilding has been discussed by H. Dutilleul.[2] In his opinion the bend test provides a good indication of weldability. Not only the ductility but the load-elongation relationship in the bend test is important, according to this investigator. However, the bending load-elongation diagram obviously is changed in course at the first crack, so that this method has no greater value than observation of the angle of bend. Dutilleul regards the notch impact test as very important. There was no relation between tensile elongation and weldability notwithstanding the fact that steels with 70,000 lb./in.^{2} tensile strength combined with low elongation often were difficult to weld. The author also found that tensile strength, of itself, was no indication of weldability, provided carbon and chromium were not used to raise the strength. Nickel and to some extent manganese had a good effect on weldability. The same ideas underlay the development of the German low-alloy steels (St 52) having a tensile strength of 74,000 lb./in.^{2}

Fundamental research has been conducted by E. Stursberg[3] on the welding of higher carbon steels. The met-

* Fortschritte in der Schweisstechnik im Zweiten Halbjahr 1937, *Stahl und Eisen*, **58**, No. 12, pp. 323–327, March 24, 1938. Translated by G. E. Claussen, Research Assistant, Welding Research Committee.

allurgical characteristics of weld-metal and base metal have been studied in welds and in drops melted from the filler rod. The base metals contained either 0.08 or 0.35–0.38 C. Four plain carbon filler rods (up to 0.58 C) and four alloy steel filler rods (medium manganese steel, chromium-nickel steel and nickel-molybdenum steel) were used with ratios of oxygen to acetylene of 0.8, 0.9, 0.95, 1.0, 1.1, 1.2, 1.4 and 1.6. It was found that a neutral flame is not necessarily obtained with a ratio of 1:1, but depends on the composition of base metal. Excess acetylene must be used with the higher carbon steels in order to secure a weld with the same carbon content as base metal. The amount of excess acetylene increases with the carbon content of the steel. Strength, ductility, and notch impact value decrease as excess acetylene or excess oxygen is added to the flame that is neutral to a given steel. Maximum tensile strength was obtained with excess acetylene (O_2:C_2H_2 = 0.95) with both plain carbon and alloy steel rods. The necessary carbon content in the plain carbon rods is higher than in the alloy steel rods. On the contrary, excess oxygen (5 to 10% excess O_2) is necessary to secure maximum elongation in the tensile test and maximum notch impact value. Stursberg believed that sufficient carbon must be present in alloy steel rods, especially rods with Si and Mn, to prevent loss of alloying elements, depending on the oxygen adjustment. In general a mixture ratio (O_2 to C_2H_2) of 0.95 to 1.05 was best, the higher oxygen ratios being desirable for the alloy steel rods. According to Stursberg, the properties of a weld improve as the hardness of weld, heat affected zone, and base metal approach each other. The conclusion to be drawn is that perfectly satisfactory welds may be made in plain carbon steel containing 0.35 C, the chromium-nickel and medium manganese steel rods being best. Stursberg also showed that bubbling and sparking of the weld puddle is due not alone to evolution of water vapor (H_2O) but to the iron oxide-iron carbide reaction as well. The drops from unkilled, low-manganese rods are coated with a viscous film. In the presence of sufficient silicon and manganese the slag accumulates in small localized areas but the weld puddle is not contaminated.

2. METHODS

A new method of boiler welding which is used in America is described by R. Rist.[6] A powdered flux is spread in the gap between the plates and a bare electrode is used. The action is the same as with covered electrodes. It is not arc welding in the strict sense of the term because the slag is melted by heat developed at the contact of electrode with plate. The molten slag then takes part in developing the heat and in securing good fusion of weld-metal with plate. The unmelted slag is removed. The author cites a plate 2 inches thick welded with a rod $^1/_2$ inch diameter. No further details were supplied by the author.

The so-called activated oxyacetylene welding was dealt with by C. F. Keel[6] in an earlier paper. More recently he[7] has dealt with flame adjustment and filler rods. On the basis of theoretical considerations Keel shows that with an oxygen excess of 25% or 10% and sufficient silicon and aluminum, an oxidizing flame is not a disadvantage. As a matter of fact, higher welding speeds are attained. However, tests on a high tensile steel showed that loss of carbon and manganese, as well as of silicon and aluminum, is much higher with the oxidizing flame than with the customary flame adjustment, and probably a higher iron oxide content can be expected, too. Nevertheless, the properties of welds made with the oxidizing flame were about the same as the properties of ordinary welds. The filler rod contains 0.27 C, 0.80 Mn, 0.25 Si, 0.25 Al, and the tensile strength (reduced section) is 89,000 lb./in.^{2} with 10% excess oxygen.

The extensive use of clad steels in chemical apparatus gives importance to a report by H. V. Inskeep[8] on the flame cutting of stainless materials and nickel-clad steels. Previously the cladding was chipped off before flame cutting from the clad side. The new method involves flame cutting from the unclad side, which avoids the necessity of chipping off the cladding. Special precautions must be observed. The torch is inclined 10° in the direction of the cut. In this way the first material cut is unalloyed steel. The slag and molten iron from the cut steel cuts the cladding. The tip and oxygen pressure must be larger than for steel, and the cutting speed is slower, for both machine and hand cutting. At the end of the cut the same rule applies as at the beginning; that is, the angle of torch is increased. If the plate is clad on both sides, the cladding must be chipped or otherwise mechanically removed from one side before flame cutting. If the stainless cladding is not stabilized with titanium or columbium, flame cutting decreases the corrosion resistance. No pick up of iron or carbon by the cladding was detected.

F. Golling and P.Tulacz[9] have developed a welded rail joint in which the head of the rail is butt welded. The web and foot are not butt welded. Instead, a foot plate is fillet welded to the foot. This joint behaved well under impact, but cracks appeared in the welded head during service which were ascribed to fatigue. Accordingly, the web was welded on both sides. The resulting joint was satisfactory in service. The authors point out that if the joint is made too stiff the rail is likely to fail outside the joint. Of all the thermit, arc and oxyacetylene welded joints installed in Poland and Hungary since 1934, the percentage of fractures has been: oxyacetylene welded = 0.45%, thermit welded = 0.8% and arc welded = 6.8%.

Rails with high wear resistance are particularly adapted to the welding process described by W. Ahlert.[10] The usual thermit process is said to be unsuited for high strength rails because the welds are brittle. The so-called combined thermit process in which the head is pressure welded and the web and foot are thermit welded also is not suitable because a good pressure weld is difficult to secure in high tensile steel. In this process the rail head for a short distance back of the end of the rail is heated to a temperature between liquidus and solidus in which the steel is pasty. Then the weld is made with thermit steel. Pressure is applied to the joint and, when it is cool, the excess thermit is ground off the head of the rail. The surface hardness of the joint is uniform and the strength is satisfactory. It is easy to see that this complicated method of welding may be replaced by flash welding.

A thorough discussion of the repair of rails, crossovers and switch points is given by H. Frankenbusch,[11] who deals with cracks, flaking and chipping of the rail ends. The size of tip must be chosen with the cross section to be welded in mind, in order to obtain good penetration yet to prevent slopping of the weld-metal over the edge of the rail or point. The filler rod must be selected in accordance with the hardness of the rail. If the filler metal is too soft, dents will appear in it. If the filler metal is too hard, dents will appear in the rail just beyond the deposit. German conditions usually require a rod with 0.8–0.85 C, 0.20 Si, 0.40 Mn, 0.4 Cr (Rod GA 3). Building up the side of a rail or point requires the same precautions as in building up the top. Sometimes a special

torch is used. After being welded the deposit is filed or otherwise brought to the proper shape. The greatest care is necessary to obtain a deposit without bulges. From the economic standpoint welding is most advantageous. A crossover weighing 1000 lb. can be made as good as new by applying about $6^1/_2$ lb. of weld-metal.

To a certain extent, the hand apparatus for carbon arc welding which is recommended by E. Thiemer[12] is a substitute for automatic welding machines for long welds. The device consists of a water-cooled holder for the carbon combined with a similarly cooled magnetic blow coil. The welder is protected from the great heat evolved by the carbon arc by means of a shield attached to the long handle with which the device is equipped. The welding head may be balanced by a counterweight, if necessary. High-grade welds can be produced with a suitable flux.

3. METHODS OF TESTING

An important factor in the properties of welds is the distribution of elements in the joint. Tests by A. M. Portevin and A. Leroy,[13] which are being continued, have lead to the development of a suitable method of analysis. Specimens weighing 10 milligrams are drilled from the weld by means of a special machine and are analyzed by titration and colorimetrically. Manganese and chromium can be determined to 0.01%; sulphur and phosphorus to 0.001%. There was an irregular distribution of manganese in a gas weld made with a rod containing 0.48 C, 0.20 Si, 1.10 Mn, 0.015 P, 0.016 S. In the weld itself there was 0.76 to 0.85 Mn, whereas the manganese content in the fusion zone was 0.9 to 1.10%. The customary methods of chemical analysis revealed 0.81% Mn in the weld.

The relation between thickness of fillet weld and strength of the joint has been investigated by H. Koch[14] on cruciform specimens made by qualifying welders. He showed that the breaking strength per unit area decreased nearly in direct proportion as the thickness of the weld was increased. Whereas Koch explained his results on the basis of poorer penetration with increasing thickness, the reviewer is of the opinion that, despite this important effect, the effect of the shape of the fillet weld is more vital. With strongly convex beads, the outside portion takes a relatively small portion of the load, yet introduces considerable bending stresses. Koch also showed that if the two welds are of different thicknesses, there is a decrease in unit strength if the difference in thickness exceeds 0.06 inch. The effect is greater with mild steel than with low-alloy, high-tensile steel.

4. PROPERTIES OF WELDS

The gas welding of Si-Mn and Cu-Mo steels for boilers and Cu-Mo and Cr-Mo steels for superheaters has been investigated by G. Czternasty.[15] It was found that filler rods of the same composition as base metal were not entirely satisfactory. Good results with Si-Mn steel were secured with a rod containing 0.14 C, 0.40 Si, 1.00 Mn, 0.80 Ni, 0.10 Cr, 0.40 Cu. For molybdenum steel a rod with 0.15 C, 0.42 Si, 0.45 Mn, 0.77 Cr, 0.46 Mo was suitable. The yield and tensile strengths were satisfactory in the as-welded condition, but the notch impact value was comparatively low. Annealing improved the mechanical properties. In contrast to A. Matting and H. Otte,[16] Czternasty found that annealing and hammering the welds had a bad effect on mechanical properties. The yield strength of the weld at elevated temperature was a little better than base metal. With Cu-Mo and Cr-Mo steel tubes, a weld-metal with the same composition as base metal gave good results. The creep velocity of the weld was slightly higher than that of base metal. The tests showed that good properties could be obtained on field welds in Cu-Mo steel. The Cr-Mo steel tended to air harden and was not suited for field welding. Several installations are described. The author found considerable loss of silicon and manganese in welding Si-Mn steel, but the carbon content increased. On the other hand, with Cu-Mo steel there was considerable loss of carbon, but no appreciable loss of Si and Mn. It should not be assumed that these peculiarities are connected in any way with the steel. Furthermore, the unwelded 1.18 inch Cu-Mo plate used by Czternasty had a tensile strength of 61,000 lb./in.^{2} and in two instances failed at small angles in the bend test. Evidently, the quality of the base metal used in the investigation was not very high.

R. Hessler[17] studied the possibility of using flame cut edges without further machining in boiler construction. The following official tests were made by two firms on two different types of boiler steels (M I and M II): tensile, cold bend, notch impact, drift pin, riveting, microstructure, in such a way that the heat affected zone played a part in the tests. It was shown that flame cut edges may be made as sharp for calking as machined edges. All specimens were allowed to remain 14 days at room temperature to provide opportunity for aging, if any. The flame cut surface of steel M I had a slightly higher yield and tensile strengths, but slightly lower elongation and reduction of area than uncut metal. There was no practical difference in the bend angle of flame cut and planned surfaces. On the whole, the bend elongation was higher for the flame cut than for the machined surface. Flame cutting lowered the notch impact value 2 mkg./cm.^{2} Bend tests on specimens with one machined edge and one flame cut edge resulted in no cracks. With a few exceptions the results[18] on steel II coincided with steel I. However, flame cut surfaces made with acetylene or hydrogen as combustible had higher elongation and reduction of area as well as higher yield and tensile strengths, than uncut metal. The same was true of notch impact value, which was slightly increased with acetylene but increased greatly with hydrogen. The conclusion to be drawn from both series of tests is that flame cutting without notches does not damage the mechanical properties of unalloyed steel with up to 0.18 C. Riveting and calking may be performed with flame cut edges in the same way as with machined edges.

The effect of flame cutting on the mechanical properties of a low-alloy steel containing 0.12 C, 0.62 Si, 1.00 Mn, 0.26 Cu was determined by R. Dümpelmann,[19] who used acetylene, hydrogen and illuminating gas for the preheating flame. In comparison with milled specimens, flame cut specimens of plates 0.4, 0.8, 1.2 and 1.6 inches thick had slightly higher yield and tensile strengths. Differences in elongation reduction of area, and notch impact value were negligible. Bend specimens in 1.2-inch plate could be bent 180° parallel to the direction of rolling without cracks. Perpendicular to the direction of rolling several specimens cracked. The as-cut surface had 36 to 50 Brinell units higher hardness than unaffected base metal. Polishing decreased the hardness considerably and the removal of a layer 0.06 inch thick by planing produced a surface having the same hardness as unaffected base metal. The differences between the different preheating gases were not important, but hydrogen appeared to have a greater effect on the flame cut surface than acetylene and illuminating gas.

Subaqueous cutting at different depths was discussed by J. B. Arnold.[20] Difficulties were encountered with acetylene as preheating gas because carbon monoxide was formed and the flame backfired. Therefore, hydrogen was used. Further difficulties were had with flame adjustment at depths greater than 50 feet; it was at first impossible to ignite the gases on account of water pressure. The results did not show whether gas consumption changed with depth. However, beyond 56 feet there was a large increase in oxygen and hydrogen consumption. The ratio of hydrogen to oxygen in the preheating flame varied between 3.4 and 3.7; static water pressure had no effect.

A comparison was made by Y. Mercier[21] among the results of left-hand, right-hand, and two-torch vertical oxyacetylene welding of soft steel. In agreement with experience in Germany the right-hand and two-torch vertical methods are best. In all processes heat treatment of the weld at the upper critical point improves the mechanical properties. Even by stress relieving at 650° C. Mercier observed a surprising increase in notch impact value, which was nearly the same as after normalizing. The great difference in notch impact results between normalizing for 3 and 10 minutes was explained by Mercier on the basis of grain growth. The two-torch vertical method is the most economical and the gas consumption is only a fraction of that in left- or right-hand welding. The welding speed is also higher, which may be due in part to the smaller volume of the X weld compared with the V weld.

With the aid of measurements of electric resistance. G. A. Ellinger and L. C. Bibber[22] studied the corrosion of welded austenitic chromium-nickel steels with low carbon content in HNO_3, HCl and a solution of copper sulphate and sulphuric acid. In agreement with other investigators it was found that boiling concentrated NHO_3 rapidily attacked 18–8 having carbides in the grain boundaries. This attack was found after heating to 650° C., but the weld-metal was unattacked whether or not it was heated to 650 or 980° C. The $CuSO_4$-H_2SO_4 solution had little effect on base metal or weld. The most active attack of base metal and weld was observed in HCl. The untreated weld-metal was more rapidly corroded than base metal, but after heat treatment the reverse was true. The HCl test is of little value in the authors' opinion, because the surface is uniformly attacked. Its structure accounts for the higher corrosion resistance of weld-metal compared with base metal, for there are areas of delta iron in the austenite of the weld-metal in which the carbides precipitate, in this way protecting the austenite crystals from intergranular corrosion.

The intergranular penetration of 50% tin solder into unalloyed and alloy steels has been investigated by G. W. Austin.[23] Tensile tests showed that pure, unalloyed low-carbon steel, as well as corrosion- and heat-resisting steels are less prone to intergranular penetration of solder than high-carbon steel. In alloy steels the attack increased as hardness and secondary grain size increased. There was no connection between the tendencies to overheating or temper brittleness and the intergranular penetration of solder. The decrease in elongation and, to some extent, of strength is caused primarily by solder in the grain boundaries. In the discussion of Austin's paper it was brought out that tin-rich solders had a greater tendency toward intergranular penetration than high-lead solders. With different solders the attack decreases in the following order: tin solder, tin, cadmium, bismuth, lead. The discussion also showed that stress is essential for the intergranular penetration of solder. Austin recommended, therefore, that steels sensitive to solder should not be used where soldering was done under tensile stress.

Examples provided by A. Leroy[24] show that in laboratory corrosion tests of welds it is often difficult to duplicate service conditions. The first example was a tank for nitric acid made of stainless chromium-nickel steel in which there was pronounced corrosion at the welds. Tests in HNO_3 of different concentrations and degrees of purity showed that dissolved aluminum in combination with high acid concentration caused the corrosion of the weld. A colloidal protective layer was formed on the base metal but not on the weld. Possibly the low chromium content (17.5%) of the weld was a contributing factor. The welding process appeared to be immaterial. The second instance was a portable chlorine tank which leaked, particularly in the welds, shortly after being placed in service. Investigation revealed oxides in the weld which appeared wherever the welding had been interrupted momentarily and poor workmanship had not secured good fusion when welding had been started once again. As a result there were slag inclusions which lowered the corrosion resistance. Proper repair by welding enabled the tank to be used for over a year.

O. Graf[25] has extended his fatigue tests on flame cut and planed surfaces to higher tensile steels. For a plain carbon steel having a tensile strength of 100,000 lb./in.^{2} he found that the endurance limit of the flame cut surface (42,700 lb./in.^{2}) was the same as for flame cut low-alloy steel having a tensile strength of 74,000 lb./in.^{2} With planed surfaces the higher tensile steel was superior to the low-alloy steel.

5. ECONOMICS

As is well known the Lindeweld method first carburizes the base metal so that it has a lower melting point before welding. For this purpose a multi-tip torch is used in which the first flame has excess acetylene and the welding flame has the usual characteristics. Right-hand welding is generally used. The speed of the Lindeweld process has been determined by E. Suris.[26] In plates $^3/_8$ inch thick a weld 3.3 feet long can be made in 13 minutes with an acetylene consumption of 1.16 cu. ft.; a weld of the same length can be made in $^3/_{16}$-inch plate in 6 min. using 0.56 cu. ft. acetylene. According to C. F. Keel,[27] the values for ordinary welding are 30 minutes and 3.2 cu. ft. for $^3/_8$-inch plate, and for activated welding 24 minutes and 2.6 cu. ft. acetylene. The comparison is more favorable for the usual and activated processes with thinner plate. Although the reviewer feels that the reported values for the Lindeweld process are a bit optimistic, the economy of the process cannot be disregarded.

The relative cost of acetylene, propane and illuminating gas for flame cutting has been determined by C. F. Keel.[28] The price of acetylene is higher but it is more economical than the other gases because the preheating flame is hotter, which is reflected in higher cutting speeds and a smaller consumption of oxygen and lower wage charges. The total cost for illuminating gas in cutting plates 0.24, 0.32 and 0.50 inch thick is 28, 40 and 47% higher, respectively, than for acetylene. The calculation does not consider fixed charges such as installation and maintenance of generators, etc.

6. MISCELLANEOUS

The relationship in low-alloy steel between welding qualities and the properties of the weld are discussed by

G. Bierett.[29] It is well known that craters, porosity, slag inclusions and similar defects have a bad effect on fatigue value. Grain size and structure, which are related to the charge, are important for sensitivity to welding cracks. The base metal and filler metal, therefore, should be matched. Mechanical considerations, such as shape of weld, also play an important part. Furthermore, the capacity for deformation (ductility) at room temperature is unrelated to cracking of the weld. Another type of crack occurs in the hardened heat affected zone. The shrinkage stresses perpendicular to the weld increase as the size of the heating zone is decreased. The effect of the size of the heated zone increases as the strength of base metal increases. With loads perpendicular to the weld the heat affected zone is particularly vital since, with its high hardness, it has the smallest capacity for deformation and becomes the weakest part of the joint, especially if any other factor is present to favor cracks near the weld. These unfavorable conditions are magnified if thick sections are welded to thin without special precautions. The causes of hardening in the heat affected zone must be understood before cracking can be dealt with effectively. The smaller the ratio between diameter of electrode and plate thickness, the harder and more abrupt will be the heat affected zone. Bierett believes that by decreasing the shrinkage stresses, we decrease the danger of cracking at the same time. The reviewer cannot agree with the term "Stress Decrease" applied to stress relief by deformation of the softer parts of the joint.

According to tests by L. DeJessey,[30] the characteristics of the heat affected zone in flame cutting depends on the conditions of cutting. With different steels the most favorable cutting conditions result in heat affected zones at least 0.03 inch deep in 1-inch plate. Up to 0.7% C has no effect on the depth of the heat affected zone; between 0.7 and 0.9% C the depth increases, but decreases again to the same value as in low-carbon steels when the carbon content has reached 1.2%. The larger the cutting speed, the shallower is the heat affected zone. The preheating flame exerts a greater effect in heating the base metal than the cutting jet. Therefore, the preheating flame should be as small as possible. The purity of the cutting oxygen is most important. The lower the purity, the greater is the depth of the heat affected zone. The oxygen should have a purity of at least 98%. The oxygen pressure is of secondary importance. As the pressure is raised to 43 lb./in.^{2} the heat affected zone becomes shallower. With further increase in pressure to 100 lb./in.^{2} the depth of the zone increases to the value characteristic of 24 lb./in.^{2} oxygen pressure. The absolute value of the depth is closely related in both instances to the cutting speed.

A remarkable repair job by oxyacetylene welding is described by H. Ebersberger.[31] A press crackshaft 7 inches diameter of plain carbon steel having a tensile strength of 71,000 lb./in.^{2} broke at a fillet on the drive side. The fracture was conically scarfed to an angle of 20° and welded with an alloy steel rod (GV_2 type) 0.24 inch diameter. The shaft was rotated as the bead was deposited in concentric rings. In this way the distortion of the shaft was kept to a minimum. At all times the weld was kept hot by means of the torch and the shaft itself was cooled by means of water. The weld was made by two welders without interruption in 18 hr. After cooling to 500° C. the weld was reheated to 870° C. to refine the grain structure. Fifteen days later the shaft was back in service. The repair charge was 25% of the cost of a new shaft without considering the saving in time. The welded shaft has given long service without trouble.

The literature on the corrosion resistance of welded joints in all kinds of steels and alloys has been summarized by W. Spraragen and G. E. Claussen.[32] The whole literature up to the end of 1936 has been summarized and is of particular interest. Another review of literature on Shrinkage Stresses in Welding up to the end of 1936 has also been prepared by W. Spraragen and G. E. Claussen,[33] which likewise shows the same great care as previous reviews. Everything that is known on the subject is summarized.

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WELDING HANDBOOK

The Welding Handbook of the AMERICAN WELDING SOCIETY will be available about July 1st. The book will contain some 1200 pages of the most up-to-date technical information available on welding. It was written by 90 experts and reviewed by nearly 300 other specialists, thus representing the work of nearly 400 people. Two years were consumed in the preparation of this monumental treatise on welding. Owing to the enormous expense of preparation, a limited edition has been prepared and will be offered for a short time at $6.00 a copy. Copies may be reserved by sending checks to the AMERICAN WELDING SOCIETY, 33 West 39th Street, New York, N. Y.

FATIGUE TESTS OF WELDS AT Elevated Temperatures*

By A. AMATULLI† and PROFESSOR O. H. HENRY‡

SUMMARY

THE endurance limit of polished specimens 0.300 inch diameter machined from mid depth of a butt weld in plain carbon steel (0.18 C) made with covered electrodes was 35,000 lb./in.^{2} at 20 and 200° C. and 41,000 lb./in.^{2} at 300° C. The endurance limit at 500° C. was not determined but was much lower than 36,000 lb./in.^{2} The stationary cantilever type of fatigue machine was employed, the plane of maximum stress passing through the center of the weld. Fatigue failure generally occurred in the vicinity of the scarf. The weld-metal had a higher static tensile strength than base metal.

FATIGUE PROPERTIES OF WELDS

The endurance limit of welds in mild steel is usually lower than the endurance limit of plate metal. Endurance limits of 16,000 lb./in.^{2} for bare wire and 30,000 lb./in.^{2} for covered wire are common values for arc welding. These values are from 60 to 90% of the endurance limit of the base metal of mild steel. Limiting fatigue stresses for gas welds usually fall between these two limits. In Germany endurance limits of 34,100 lb./in.^{2} have been obtained for gas welds in mild steel plates. This is 86% of the endurance limit of the plate metal.

It has been noted that bare wire welds in foreign countries have given better endurance limits than bare wire welds made in this country. The reverse is true for welds made with covered electrodes. In the latter case the difference may be due to the differences in steels, welding techniques and the possible superiority in the type of coatings in this country.

The endurance limits of welds are not always the same as unwelded steels. This may be due to several reasons the more important of which are:

1. Poor penetration, that is, lack of good fusion along the scarves.
2. Internal defects, such as pores, slag inclusions, oxide spots and blow-holes.
3. Interrupted seams, which are essentially "stress raisers" and should be avoided wherever possible.
4. Differences in grain structure and hardness between the weld and base metal.
5. Internal stresses caused by the heating and cooling of the weld section.

All these defects may lower the endurance limit of welds. Poor penetration has decreased the endurance value of welds 50 per cent or more. Some investigators showed that blow-holes and porosity had little or no effect on the endurance ratio of welds. Although they should be avoided, they are not as important as other factors from the standpoint of endurance limit.

Increasing the fatigue strength of welds by heat treatment is also possible. Another method of improving the fatigue properties of welds is by mechanical treatment. Welds mechanically treated by peening have shown an improvement. One investigator found that peening raised the endurance limit of welds, tested by rotating cantilever, from 18,000 lb./in.^{2} to 20,000 lb./in.^{2} for bare wire electrodes. Further investigation showed that peening each layer of beads had the same effect as peening just the outer layer. Peening refines the grain structure and it was found that the coarser the grains at the surface layer of the weld the lower the fatigue strength in reversed bending.

Hot forging has been found to increase the fatigue limit of welds up to 20% for backhand welds and only 10% for forehand welds. Other investigators found increases of 75 to 100% in fatigue values due to hot forging.

From the mass of accumulated data on the fatigue of welds, it has been shown that the endurance limit is lower than the base or parent metal. Furthermore, heat and mechanical treatment, use of coated rods, techniques of welding and other pertinent facts concerning welding, have all been shown to have definite effects upon the endurance limit.

FATIGUE AT ELEVATED TEMPERATURES

The fatigue properties of steels, when subjected to increases in temperature, are decidedly different than at room or temperate climatic conditions of temperature. When metals are subjected to either static or fatigue stresses at various degrees of elevated temperatures, factors such as plastic flow, plastic strain and creep have a marked effect upon their physical properties. Static, impact, creep and fatigue tests have been made of unwelded steels at low and high temperatures but in the case of welds there is record of only one investigation of fatigue at elevated temperatures.

The majority of fatigue tests of steels at elevated temperatures have been made on rotating-bend fatigue machines. From a summary made by two German investigators, M. Hempel and H. E. Tillmanns,[1] it has been shown that up to 200° C. there is either a slight increase or decrease or no change in the rotating-bend endurance limit of steels compared to room temperature. In mild and medium carbon steels the endurance limit rises slightly at 300° C. and continues to increase up to 400° C. Above 400° C. the fatigue limit was shown to fall rapidly to that of room temperature at 450° C. and far below at 500° C. No measurements were made above 650° C.

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It is interesting to note that no mention was made that flowing of the steel under stress at elevated temperature was taken into account except by Hempel and Tillmanns. The maximum value of the ratio of endurance limit to tensile strength, both measured at the same temperature, was obtained at 400° C. The axial stress endurance limits at elevated temperatures were generally found to be much lower than rotating-bend endurance limits. It was noted in several axial load tests at 450° C. that the broken specimens showed signs of plastic strain.

Lea and Parker,[2] made fatigue tests of welds at elevated temperatures. The tests were run on machined 70° V weld specimens 0.48 inch deep and 0.62 inch wide in a reversed bend, constant bending moment machine at 1000 cpm. at temperatures of 20, 250 and 450° C. with a 10^7 cycles criterion. The welds were made with a reversed or root run with a covered, shielded arc electrode (analysis not given) in mild steel plate (tensile strength 61,500 lb./in.²). The results they obtained for fatigue limit are as follows: at 20° C. the endurance limit was 23,300 lb./in.²; at 250° C., 27,300 lb./in.² and at 450° C., 23,500 lb./in.² The results show a 17% increase in fatigue limit at 250° C. over that of room temperature, but at 450° C. the fatigue limit approximates that at room temperature. The fatigue behavior of welds at elevated temperatures are not unlike unwelded steels under the same conditions of test.

In the fatigue of metals at elevated temperatures, creep plays an important part, since both fatigue and creep involve the time element, that is, "long time." In the case of steels, creep is unimportant in relation to fatigue at air temperatures but at high temperatures it takes precedence and it is probably the more important factor in the case of soft metals at air or moderate temperatures. Creep is usually defined as the deformation of a material occurring with time under and due to an externally applied constant stress, whether deformation be of plastic or viscous flow. As defined, creep is not meant to include dimensional changes with time due to internal forces consequent on structural or constitutional changes. Since in fatigue stress the load is repeatedly applied for a large number of cycles which involves long time, the metal will tend to creep.

Creep, like fatigue, also is expressed in the form of a limiting stress. Similar to endurance limit, the limiting creep stress is expressed in pounds per square inch at some degree of temperature with a rate of strain (creep velocity) as a criterion. For example, several specimens tested at 400° C., by Appaly, a German investigator, for 800 hours with a creep velocity of 10^{-5}% of specimen gage length per hour, were found to have a limiting stress of 12,800 lb./in.² for plate metal and 14,200 to 15,700 lb./in.² for the weld specimen. As a rule, in creep tests, the temperature and stress are fixed and the rate of creep determined. This was the case in tests performed by White, Corey and Clark of the Edison Electric Institute. They made tests at 450° C. and 15,000 lb./in.² tensile stress and at the end of 100,000 hours found creep rates of 1.1, 1.2 and 1.5% for pipe material, welded pipe-to-pipe and welded pipe-to-casting, respectively.

Although both fatigue and creep have been investigated individually, no research has been carried out in which they have been correlated. Just what relation endurance limit stress bears to limiting creep stress is still unknown. What is more important in fatigue and creep at elevated temperatures is whether or not large creep velocities will exist at the endurance limits of corresponding elevated temperatures. In other words will there be a large creep velocity if a metal is stressed at its endurance limit at a high temperature? This is one of the questions that must be left for future study. What is definitely needed is a more complete summary and correlation of the action of high temperatures on the physical properties of metals. Only in this way can a code of working stresses be formulated so that the engineer can select those materials best suited for his purpose.

2. Lea, F. C., and Parker, C. F., *Proc. Inst. Mech. Engrs.*, **133**, 15-66 (1936).

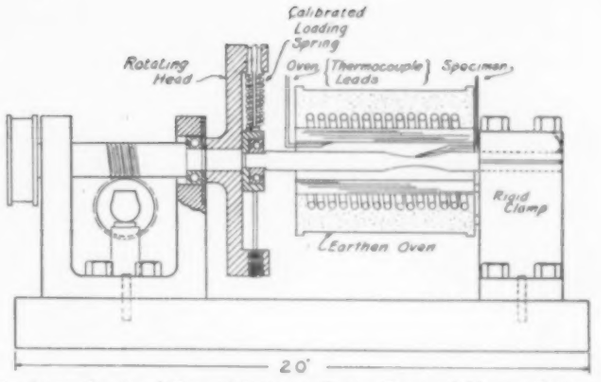


Fig. 1 (*a*)—Sectional View of Rotating-Spring Reversed-Flexure Fatigue Testing Machine

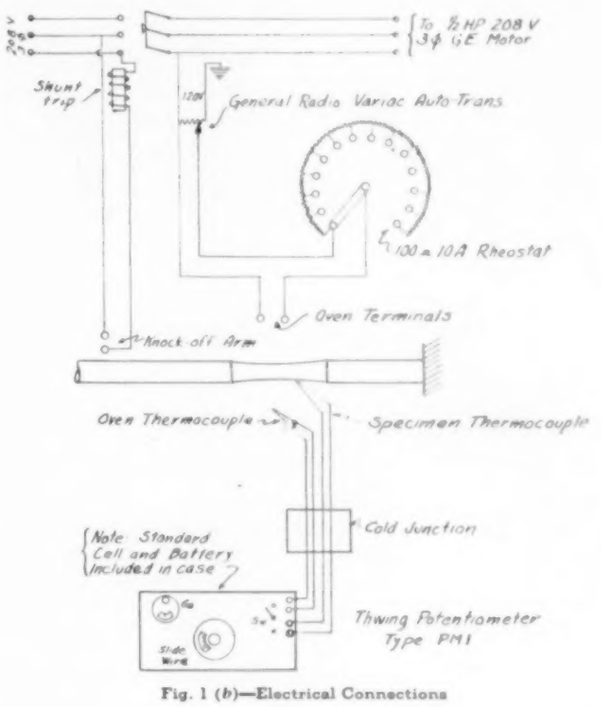


Fig. 1 (*b*)—Electrical Connections

TEST PROCEDURE
FATIGUE TESTING MACHINE

The fatigue machine used for the tests is a Rotating-Spring Reversed-Flexure type manufactured by J. B. Hayes, Inc., of Urbana, Illinois. The machine is identical to those used by Professor H. F. Moore at the University of Illinois. A partial cross section of the machine is shown in Fig. 1(*a*). As the pulley rotates the circular rotating-head, the end of the specimen carried in the ball-bearing race describes a circle whose radius is equal to the eccentricity of the race due to the load applied by the calibrated spring. Since the other end of the specimen is fixed in the rigid clamp, causing a cantilever effect, the fibers of the specimen will have passed through alternate stages of maximum tension and compression for one complete revolution of the rotating head. The form

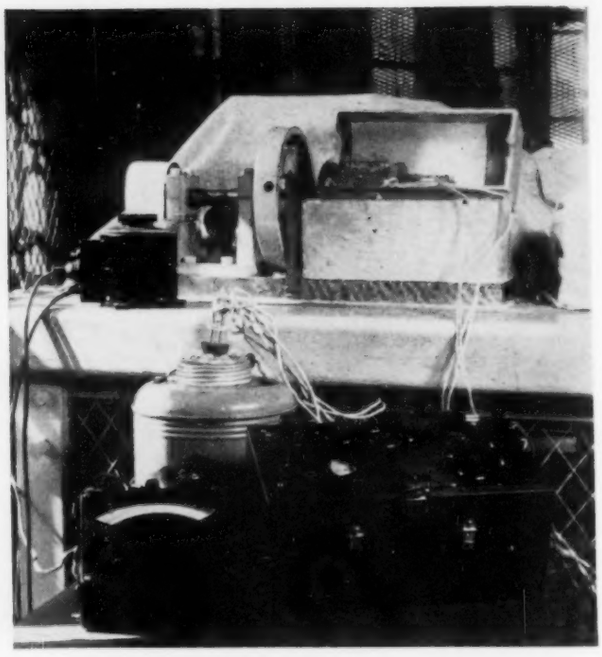


Fig. 2—Apparatus

and dimensions of the specimen are shown in Fig. 4. In order to determine the maximum stress in the extreme fibers at the throat or critical section of the specimen, the flexure formula for cantilever beam is used.

The magnitude of the load applied to the specimen was determined by noting the deflection produced in the spring. The machine was equipped with two springs; a 40-pound and a 60-pound spring. The springs were calibrated in a special jig and Ames gage.

During the tests, the machine was frequently stopped during the first few hours of the test and the load checked. If the load fell off because of the yielding of the specimen, the load was increased to its desired value. Usually the load remained constant after the first few hours of test.

HEATING CHAMBER

The sectional view of Fig. 1 (*a*) shows the oven used for tests at elevated temperatures. Figure 2 shows the box used to surround the oven and the rigid clamp. The box was made of $^3/_8$-inch transite with a cover and an opening at the ball race end for the protrusion of the specimen. In the space between the oven, rigid clamp and the box, oven and base of the machine, rock wool (shredded asbestos) was packed. Before the cover was placed in position, several thicknesses of asbestos paper were placed over the oven and the rigid clamp.

When a specimen was placed in the machine, it was inserted through an asbestos washer $^1/_4$ inch thick. This washer fits snugly on the specimen and moves in a circular motion with the specimen in the space between the oven and the specimen opening in the box. The purpose of the washer was to eliminate the entrance of air currents blown by the rotating head when in motion. It also partially protected the ball-bearing from radiated heat from the oven.

In the space between the oven and rigid clamp, several thicknesses of asbestos paper were inserted to cut down the convection currents from the oven.

The rigid clamp and the bearing holders beyond the rotating head were not insulated from the steel base of the machine. The machine base rested on a thick layer of asbestos which in turn was embedded in cork which covered a table whose top was of reenforced concrete.

APPARATUS AND MATERIAL

In addition to the fatigue machine the apparatus used in connection with the tests is as follows: a Thwing potentiometer type PM 1 which included in the case, two dry cells, a standard cell and a galvanometer; two iron-constantan thermocouples, one of No. 28 B & S gage for the specimen and one of No. 22 B & S gage for the oven; a one gallon thermos jug used as a cold junction; a 100 ohm-10 ampere Ward Leonard rheostat; a General Radio 850 watt 120 volt Variac Auto-transformer and a $^1/_{1000}$ inch Ames gage with several plunger rods of various lengths. The oven used was of the electric earthen type having a maximum temperature range of 550° C.

Temperature Measurements.—The two thermocouples were made and calibrated by the Brown Instrument Co. The oven thermocouple was placed against the inside wall of the oven and the specimen thermocouple was attached to the throat of the specimen by means of a double layer of asbestos tape. The Thwing potentiometer was used to measure the potential across the thermocouple leads Fig. 1(*b*). A reference junction was maintained in the thermos jug by means of cracked ice. Four glass tubes closed at the bottom were inserted through the stopper of the jug. The closed ends of the glass tubes were 2 inches from the bottom of the jug and they were filled to a depth of 2 inches with mercury.

In the tests at temperatures up to 500° C. the temperature was controlled to ±10° C. The temperature variations were created by cyclic changes in room temperature, complete compensation for which could not be made.

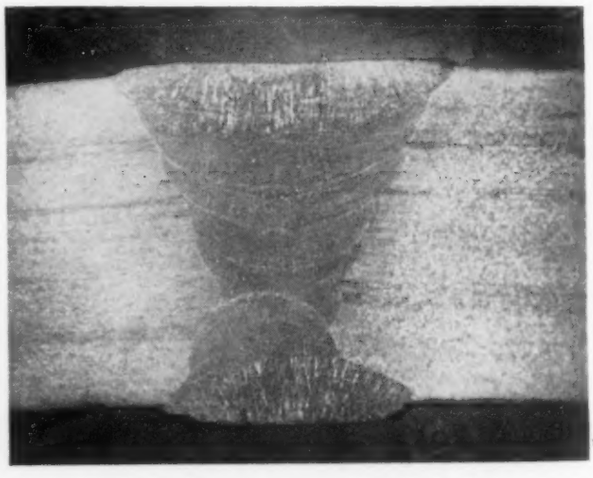


Fig. 3—Macrograph of Butt Weld. ×4

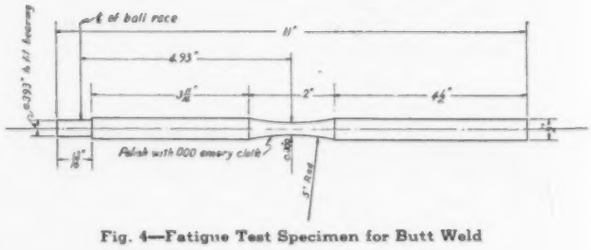


Fig. 4—Fatigue Test Specimen for Butt Weld

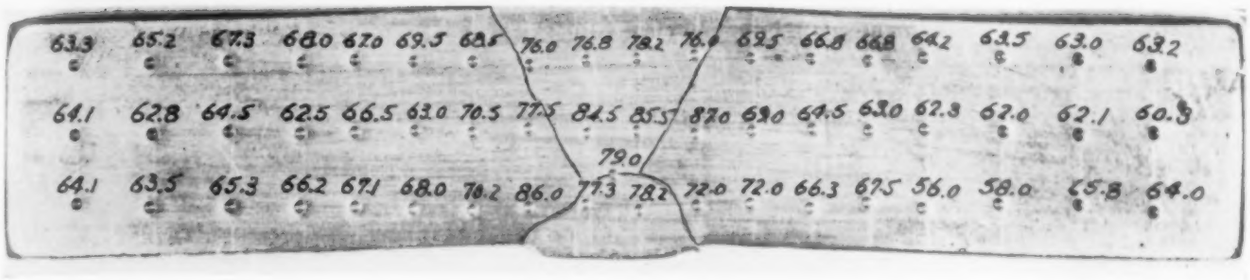


Fig. 5—Rockwell Hardness Survey of Joint

Specimens.—The specimens for this test were cut from a welded plate donated for the purpose by Mr. Everett Chapman. The welded plate was 14 x 30 x $^3/_4$ inch with a butt weld, Fig. 3, down the long dimension. The plate contained 0.18 C, 0.39 Mn, 0.019 P, 0.036 S. Covered electrodes were used (A.C., $^3/_{16}$ inch diameter at 240 amps., $^1/_4$ inch diameter at 320 amps.). The physical properties of all-weld-metal, when welding mild steel plate and stress relieved at 1150° F., reported by the electrode manufacturer are as follows:

Tensile Strength	70,000 lb. to 72,000 psi
Yield Point	55,000 lb. to 60,000 psi
Elongation in 2 In.	30 to 25%
Reduction in Area	55%
Endurance Limit	Approximately 38,000 psi

The chemical analysis of the deposit is:

Carbon	0.10–0.12%
Manganese	0.40–0.50%
Silicon	0.10%
Sulphur and Phosphorus	Less than 0.03%

The actual composition of the weld, of course, will be to some extent a mixture of this deposited metal analysis and the parent or base metal.

A tension specimen (A. S. T. M. standard 0.505-inch specimen) across the weld failed in base metal. The yield strength was 38,500 lb./in.^{2}, tensile strength = 61,500 lb./in.^{2}, elongation = 19% in 2 inches, reduction of area = 47%. A Rockwell hardness survey across the joint, Fig. 5, showed that base metal was 60 to 65 *B* Rockwell, the maximum hardness in the joint being 87 *B*. The microstructure of unwelded base metal is shown in Fig. 13. The plate, which was not heat-treated after welding, was cut into strips $^3/_4$ inch wide, at right angles to the weld, and then turned down rough to $^9/_{16}$ inch in an engine lathe. They were then placed in a Rivett, 1 inch capacity, bench lathe and turned to $^1/_2$ inch diameter. The specimen was then etched in the middle with a 10% solution of nital. The etching brought out the weld, and a center punch mark was made at the center of the weld. Then the necked section was turned using an arc cutting fixture constructed especially for these specimens. The specimens were then machined for the reduced section for the ball-bearing race. Finally, the specimens were placed in a high speed lathe and polished with 000 Huberts paper. The dimensions of the specimens are shown in Fig. 4.

No defects were observed in the radiograph of the welded plate, Fig. 6. Most of the fatigue specimens

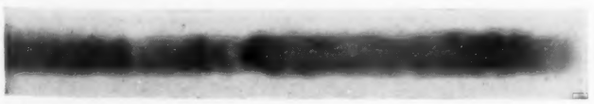


Fig. 6—Radiograph of Unmachined Weld

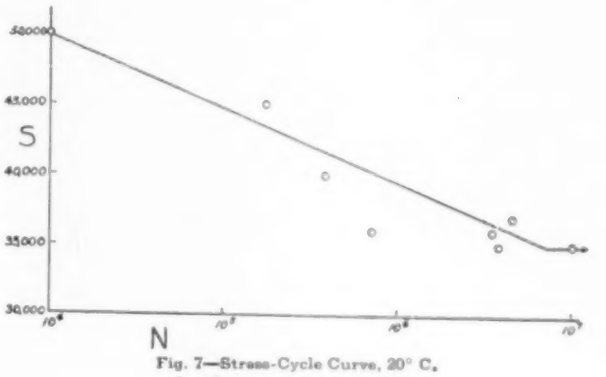


Fig. 7—Stress-Cycle Curve, 20° C.
S = Stress in extreme fiber, lb./in.^{2}
N = Number of cycles, logarithmic scale.
Arrow signifies specimen did not fracture.
Endurance limit = 35,000 lb./in.^{2}

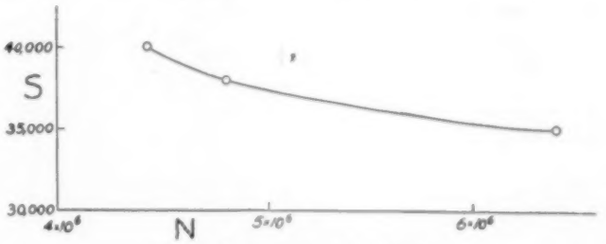


Fig. 8—Stress-Cycle Curve, 200° C.
S = Stress in extreme fiber, lb./in.^{2}
N = Number of cycles, logarithmic scale.
Endurance limit = 35,000 lb./in.^{2}

were magnafluxed using magnaflux dust suspended in a light oil prior to testing. Accumulations of powder were observed along the fusion line and in the vicinity of the scarves of all the specimens that were tested. No accumulations were found on the weld-metal. The accumulations along the fusion were not continuous and could only be interpreted as indicating some unexplained conditions, perhaps a minute defect. No defects along the scarves were observed in macro or microstructural examination.

TEST RESULTS

The results are presented in Tables 1 to 4 and Figs. 7 to 10. The endurance limit rose from 35,000 lb./in.^{2}, at 20 and 200° C. to 41,000 lb./in.^{2} at 300° C. The increase is 17%, which is exactly the same as the percentage increase found by Lea and Parker in their reversed bend fatigue tests. The endurance limits observed by these investigators were much lower than those determined in the present tests. The method of testing and the difference between the welds in the two investigations probably account for the difference in endurance limits. Insufficient specimens were available for determining the endurance limit at 500° C., although there is no doubt

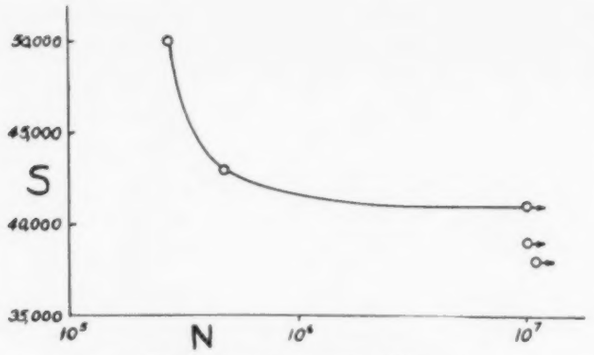


Fig. 9—Stress-Cycle Curve, 300° C.
S = Stress in extreme fiber lb./in.²
N = Number of cycles, logarithmic scale.
Arrow signifies specimen did not fracture.
Endurance limit = 41,000 lb./in.²

Table 1—Temperature of Specimens—20° C.

Number of Specimen	Computed Stress Lb./Sq. In.	Cycles of Repeated Stress	Remarks
1	50,000	10×10^3	Showed surface crack at 8900 cycles. Failed across scarf and plate.
2	45,000	176×10^3	Showed surface crack at 167×10^3 cycles. Failed $^1/_{16}$ inch from weld in plate metal.
3	35,000	10×10^6	Ran out without failure.
4	37,000	4.5×10^6	Failed along the scarf with a small section of weld-metal adhering to plate.
5	40,000	1.38×10^6	Failed in weld-metal at center. Fracture showed small area of porosity.
6	36,000	7.1×10^5	Failed in base metal $^1/_8$ inch from weld.
7	36,000	3.49×10^6	Failed in plate metal near scarf. Plane of break intersected the plane of scarf angle at top of weld.
8	35,000	3.71×10^6	Failed the same as specimen No. 6.

Endurance Limit—35,000 lb./sq. in. at room temperature (20° C.).

Table 2—Temperature of Specimens—200° C. ± 5° C.

Number of Specimen	Computed Stress Lb./Sq. In.	Cycles of Repeated Stress	Remarks
16*s*	40,000	4.25×10^6	Fracture outside edge of weld-metal in base metal. Small area near outer edge of fracture showed a blue color, which suggests that the crack propagated slowly before complete failure.
17*s*	38,000	4.61×10^6	Failure across the base metal $^1/_{16}$ inch outside of weld. Fracture clean and quite smooth.
18*s*	37,000	2.76×10^6	Failure the same as specimen 17*s*. The appearance of fracture gave no evidence of why it failed at fewer cycles of stress than 17*s*.
6*s*	35,000	6.25×10^6	Fracture slightly coarser than those above. Blue color of fractured section across the area indicated that the progress of fracture was slow. Failure occurred in base metal just outside the weld.

Endurance Limit—35,000 lb./sq. in. at 200° C. ± 5° C.

that the endurance limit is well below 36,000 lb./in.² The loads applied to the specimens at 500° C. were so high that permanent deformation occurred. Consequently, the maximum stress was not known precisely. For that matter the modulus of elasticity was not known at 500° C. At 300° C. and below, it was known that the modulus of elasticity was the same as at room temperature.

Table 3—Temperature of Specimens—300° C. ± 10° C.

Number of Specimen	Computed Stress Lb./Sq. In.	Cycles of Repeated Stress	Remarks
7*s*	50,000	2.70×10^5	Fracture along the edge of weld. Break shows slight roughness.
8*s*	43,000	4.74×10^5	Failed just outside of edge of weld in the base metal.
9*s*	38,000	11.12×10^6	Ran out without failure.
10*s*	39,000	10.01×10^6	Ran out without failure.
11*s*	41,000	10.00×10^6	Ran out without failure.

Endurance Limit—41,000 lb./sq. in. at 300° C. ± 10° C.

Table 4—Temperature of Specimens—500° C. ± 10° C.

Number of Specimen	Computed Stress Lb./Sq. In.	Cycles of Repeated Stress	Remarks
4*s*	50,000	13,510	Failure occurred in base metal outside of weld. Slightly coarse across the fracture.
12*s*	45,000	60,300	Plane of failure across plane of scarf angle in base and weld-metal. Fracture quite rough and coarse.
13*s*	42,000	105,100	Failure occurred across the scarf angle with the greater part of the break in the base metal. Break not quite so coarse as those above.
14*s*	39,000	11,200	Failed in base metal just outside of weld. Fracture parallel to scarf angle and very rough and coarse.
15*s*	36,000	10,500	Failed in weld-metal just inside of scarf angle. Fracture of very rough and coarse cross section, and plane of break parallel to scarf angle.

No endurance limit could be determined due to lack of specimens but the results obtained above definitely indicate that at this temperature the endurance limit is below that at room temperature.

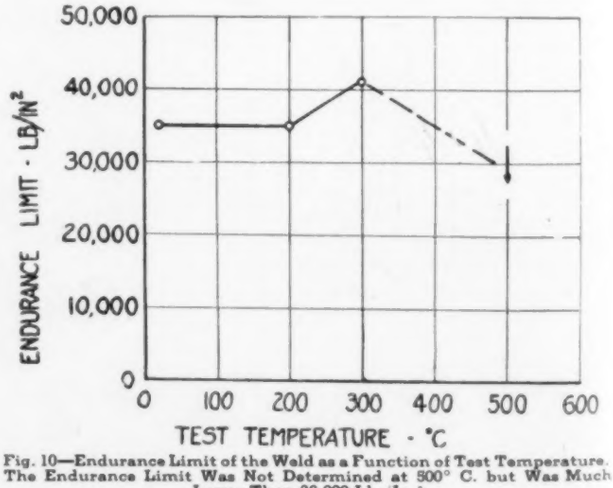


Fig. 10—Endurance Limit of the Weld as a Function of Test Temperature. The Endurance Limit Was Not Determined at 500° C. but Was Much Lower Than 36,000 Lb./In.²

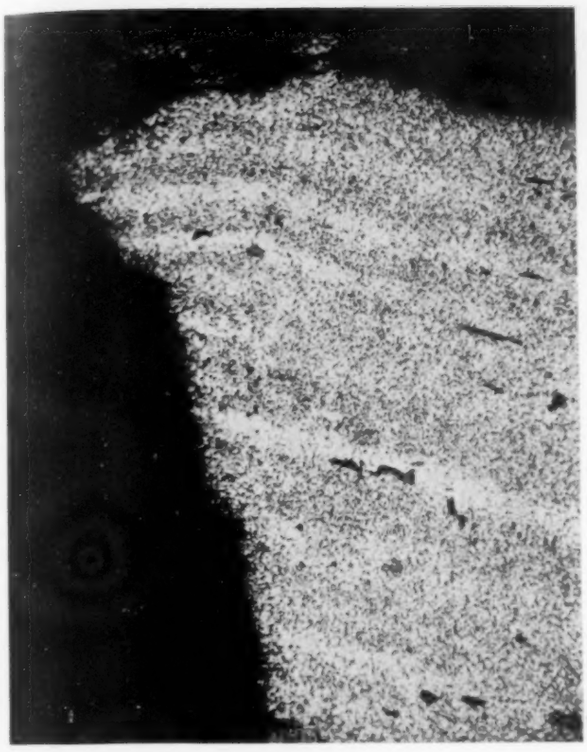


Fig. 11—Fatigue Fracture of Specimen 17 *S* (4. 61 x 10^5 Cycles at 38,000 Lb./In.^{2}, 200° C.) x 500

The fatigue fractures at 200 and 300° C. were of the same smooth character as at 20° C. The rough fractures at 500° C. indicate more likely that the stress was far above the endurance limit than that the steel was brittle. The fatigue fractures in nearly all specimens occurred in the vicinity of the scarf. The fracture of the specimen that failed through the center of the weld revealed a small slag pocket not visible in the radiograph. Although the scarf was not in the plane of maximum stress, the difference between the stress at the plane of the scarf and the plane of maximum stress was not more than 2%.

Microscopic examination of polished and etched sections of the fatigue fractures showed that the weld-metal and heat affected zone of the metal in the specimens, which represented the weld at mid depth, was finer grained than base metal. The distribution of pearlite was uniform in nearly all sections. A tiny region that appeared to have a higher carbon content was observed in one of the specimens.

Fatigue fractures were observed in the heat affected zone in some specimens and in weld-metal in other specimens. In either case the fracture traveled close to the scarf. An example of fracture occurring in the heat affected zone is shown in Fig. 11. The fracture was within $^1/_{16}$ inch of the scarf. A fatigue crack that originated in, and propagated through, deposited metal is illustrated in Fig. 12. The crack started at the surface in the upper part of the weld, and progressed diagonally across weld-metal to the scarf, beyond which it branched into several smaller cracks. In general, the cracks passed through inclusions. The micrograph also shows the transition from base metal to fine grained, heat affected zone and weld-metal. The fact that the weld was multilayer accounts for the fine grain structure.

The ratio of stationary cantilever endurance limit to static tensile strength of the butt weld was 0.57 at room temperature. Since static tensile failure occurred in base metal whereas fatigue fracture occurred in the scarf, the ratio is fictitious. In the absence of information on the static strength of that portion of the joint in which fatigue fracture occurred, there can be no objection to stating that the endurance limit of the polished fatigue specimen with maximum stress in the weld-metal and scarves is at least one-half the static tensile strength of the joint. The endurance limit of the weld, therefore,

Fig. 13—Structure of Unwelded Base Metal. x 100

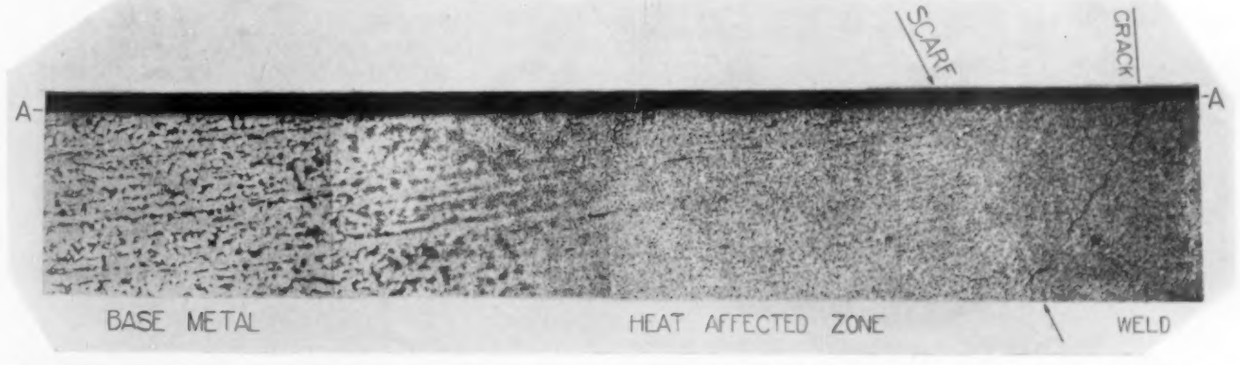


Fig. 12—Composite Photomicrograph of a Secondary Fatigue Crack in Specimen 7 *S* (0.27 x 10^5 Cycles at 50,000 Lb./In.^{2}, 300° C). Arrows Indicate the Scarf. The Specimen Failed Near the Opposite Scarf. *A-A* Indicates Surface of Specimen. x 100 in Original

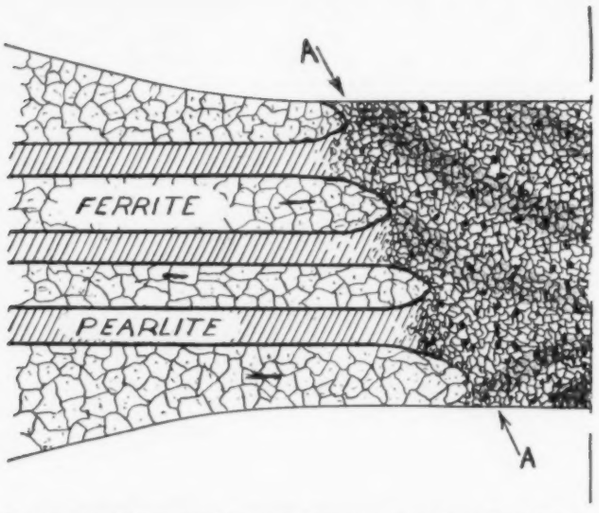
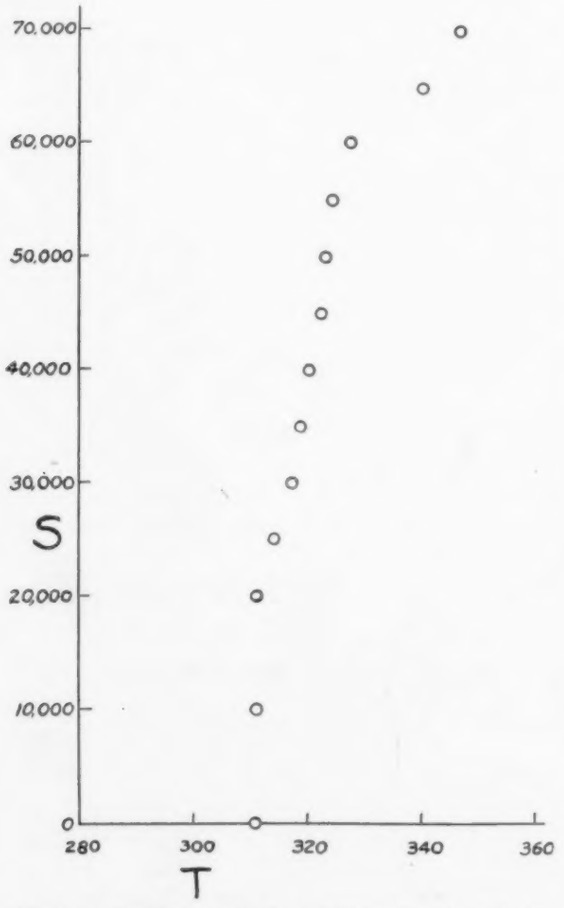


Fig. 14—Sketch Showing Change in Structure from Base Metal Through Heat Affected Zone to Weld-Metal. Arrows *A-A* Indicate Scarf and Also the Origin of Fatigue Cracks. The Shaded Bands in Weld-Metal Represent Successive Layers

was the same as would have been predicted for unwelded steel. Since the endurance limit up to 300° C. varied with temperature in the same way as unwelded base metal, the conclusion may be drawn that there is no essential difference between the endurance limit of unheat-treated, welded and unwelded steel, if multilayer welds and polished specimens are considered.



g. 15—Short-Time Test at 310° C. No Estimation of the Endurance Limit Was Attempted

S = Stress in extreme fiber, lb./in.²
T = Temperature at throat of specimen, degrees centigrade.

SHORT-TIME FATIGUE TESTS

An attempt was made to utilize the rise-of-temperature method for determining the endurance limit of the weld. A set of 3 specimens were tested by short-time rise-of-temperature method at room temperature These tests were run with the oven and insulating box in position. The specimen thermocouple was securely taped at the throat and then the specimen was placed in the machine. The oven thermocouple was already secured to the inside wall of the oven which was not turned on but which was at room temperature. The thermos jug cold junction was filled with cracked ice and water. When the specimen and oven were at room temperature the test was started. The load was applied and the motor started. After a five minute run, the potentiometer readings for the oven and specimen thermocouples were taken and recorded. The load was then increased and another run started and the above procedure repeated. These five minute runs were continued until an apparent break was noted in the relation of stress to temperature, at which time the test was concluded.

At the elevated temperatures, the same procedure was followed for the rise-of-temperature method except for several variations. After the specimen was placed in the machine and the oven turned on, the specimen was brought to the desired temperature. Since the heating medium from the oven to the specimen was air there was a lead in the temperature of the oven over that of the specimen. By observation it was necessary to determine the necessary oven temperature to maintain the desired temperature for the specimen. This required about 2 hours. The oven, the surrounding machine parts and the insulating box had to be saturated before the test was started. When the proper conditions were maintained for at least one-half hour, the load was applied to the specimen and the tests run as described above. Before each succeeding run proper adjustments were made for the temperatures of the oven and specimen. Before each set of readings were taken on the potentiometer, the potentiometer circuit was balanced against the standard cell.

The endurance limit for the three specimens at 20° C. was indicated to be 33,500 to 37,500 lb./in.² which was in close agreement with the long time tests. At 310° C., however, no endurance limit could be estimated from the results, Fig. 15.

ACKNOWLEDGMENTS

The authors wish to acknowledge their indebtedness to the following persons:

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Mr. Albert L. Colston, principal of the Brooklyn Technical High School, for permission to use equipment.

SHRINKAGE STRESSES IN WELDS

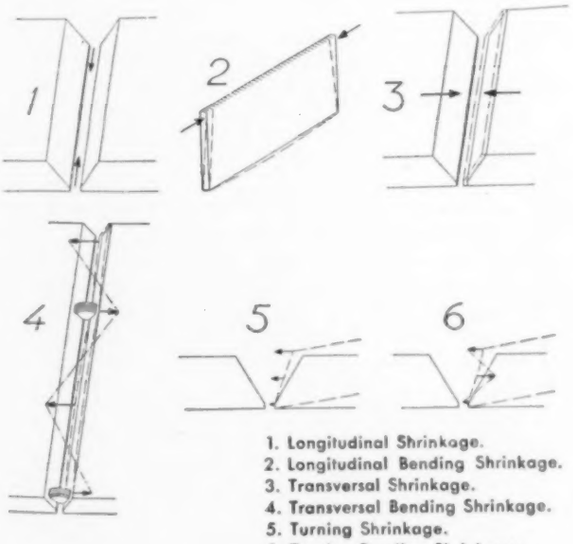
By S. A. ESKILSON

NOTE: *In the course of correspondence with Mr. S. A. Eskilson, who is associated with A. B. Svenska, Gasaccumulator, he supplied further details of his tests which were very briefly referred to in the review of literature on Shrinkage Distortion in Welding. These additional details are contained in the accompanying article, the majority of which appeared in AGA-Journal, July 1937, pp. 4–13 under the joint authorship of S. A. Eskilson and R. Gunnert. Extracts are also taken from other articles by Mr. Eskilson.*

THE Congress Number of the *AGA-Journal* published in 1936 contained a lengthy article on weld shrinkages and shrink stresses. The article defined the term "shrinkage" and various manifestations of shrinkage, which are divided into 6 cases, Fig. 1.

To illustrate these six elementary cases of shrinkage, comparative electric arc welding and oxyacetylene welding tests had been carried out, for this purpose an arc-welding firm and an impartial institution providing the results of shrinkage in arc welding or executing welds in the principal cases of shrinkage. The primary object of the investigations was to discover methods and means of avoiding shrinkage and shrink stresses, and these researches resulted in a far clearer idea being obtained of the shrinkage phenomena that arise in oxyacetylene welding and arc welding. In this particular respect special interest attaches to the results obtained in the sixth case of shrinkage shown in Fig. 1, viz., Turning Bending Shrinkage.

By turning bending shrinkage is meant, according to Fig. 1, the turning and bending effect which is caused on the edge of the joint by a transversal shrinkage unevenly distributed in the direction of the depth of the joint. In order to ascertain the stresses caused by this shrinkage in a welded [work] specimen, the method employed was to measure certain short distances along the work specimen and the distance changes that arose at these distances in consequence of the shrinkage. These distance changes were very minute and consequently the percentage of error of measurement must likewise be kept very small. A detailed account of the method of procedure employed in taking these measurements and of the results on the turning bending stresses of welds is given below.



1. Longitudinal Shrinkage.
2. Longitudinal Bending Shrinkage.
3. Transversal Shrinkage.
4. Transversal Bending Shrinkage.
5. Turning Shrinkage.
6. Turning Bending Shrinkage.

Fig. 1—Definitions

To take the method of procedure used in making, for instance, an arc-weld in a single V-gap in a 1-inch plate, this weld is done in a number of runs, which are deposited in the joint one after another, the runs already deposited being allowed to cool before the succeeding ones are deposited and shrink. This causes a tension stress in the top and root of the weld and a compressive stress between the two. A single-run weld gives rise to no such turning bending shrink stresses.

The cause of these stresses is to be found in an elastic deformation arising in the deposited metal, If, then, the stresses are made to cease, the elastic deformation must also cease and the material must thus assume the shape it would have taken if no stresses had arisen. The elastic deformation which then takes place corresponds to the stresses that have been released. If the latter elastic deformations are capable of measurement, then it is possible to gage the shrink stresses that existed prior to the release according to Hooke's formula:

$$\frac{\lambda}{L} = \frac{\sigma}{E}$$

The main object of these measurements was to gage the distance change λ along different short distances L situated in the weld and in the parent metal. Since the stresses σ that arise lie transversely across the weld and differ at different heights between the root and the top of the joint, the problem was to determine the value of λ for distances running across the weld at different heights. Five heights were considered to be most suitable, viz. the center of the plate thickness, 0.08 inch from the upper surface, and the under surface, and at each of two places just between these two. In order to ascertain the actual distribution of the stresses across the weld, it should be possible to measure up λ at each point or at any rate along as short measuring distances L as possible. The length represented by L was 0.12 inch. Since the stresses in a number of welds were probably quite small, it was agreed upon as a desideratum that stresses of 1400 lb./in.^{2} should be indicated at least as to their direction. It was, therefore, necessary that the error of measurement should be kept below or should not exceed $\pm$ 1000 lb./in.^{2} This implies an error of measurement not exceeding $\pm$ 0.1 μ (1 μ = 0.001 mm. = 0.00004 inch). By arranging the measurements in a special way, however, it was possible to make a measuring instrument with an accuracy of $\pm$ 0.3 μ sufficient for the purpose. The usual types of measuring instruments available do not, however, give such a high degree of accuracy or else are not suitable for other reasons. Instruments of this kind are mentioned by O. P. van Steewen (Teknisk Tidskrift, **65**, A345-A353, A357-A360 (1935)). On the other hand, the

Fig. 2—The Twisted Band of the Measuring Instrument

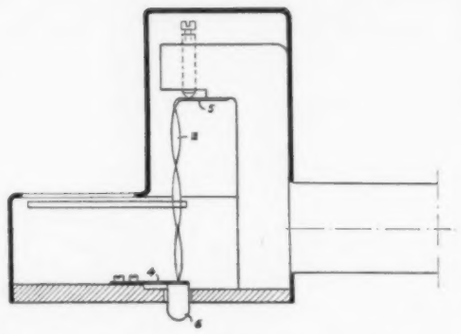


Fig. 3—Schematic View of the Measuring Instrument

gage invented and manufactured by H. Abramson was found to be a suitable instrument for the purpose.

The vital part of this instrument is the band 2, of phosphor bronze, which is illustrated in Fig. 2, drawn to a large scale. Band 2 is axially twisted in such a way that both its halves, calculated from the middle, are twisted in different directions, as shown in Fig 2. As a result of being twisted in this way the edges of each half form a spiral, while the center line A–A is practically straight. If this band is expanded in such a way as to increase the distance A–A, the band will turn around the axis A–A. If a pointer is attached to the band between these two twisted halves, this pointer will give a highly magnified indication of even the minutest variation in the distance between the ends A–A.

Figure 3 illustrates the principle underlying the actual construction of this measuring instrument. The band 2 is held at tension between the springs 4 and 5, where the measuring-pin 6 is attached to spring 4. In order, however, that the instrument could be applied to the work specimens here in question, certain special arrangements were necessary. The specimens were boiler plate (0.1 C) the dimensions of which were 11.8 x 11.8 x 0.1 inch and which had been made by welding together two plates of half the width. Four plates were made with a weld in the center, partly by arc welding and partly by oxyacetylene welding, partly in a single V-gap and partly in a double V-gap. The idea was to ascertain the turning bending shrink stresses found to arise in these plates.

The plates were severed by sawing across the weld, so that bars 1 inch wide were obtained, and these were polished on their sawn surfaces, whereas the upper and under surfaces of the weld and of the parent metal were left untouched. The turning bending shrink stresses in the plates can be released by cuts along the weld made at right angles to the surfaces of the parent metal.

The principle involved in the measurements was thus based on the gaging of the distance between different points on one of the polished surfaces and then cutting the pieces with cuts parallel to the weld and at right angles to the upper and under surfaces, after which the distances between the points were again measured. The difference in the distance between the points resulting from these two measurements represented the elastic distance change undergone by L while the plate is being cut through, this change corresponding to the stress that existed along L prior to cutting. Small conical holes were therefore drilled in the surface at a distance from one another = the measured distance 0.12 inch according to Figs. 4 and 10. Such holes should release the existing stresses as little as possible. Thanks to the conical shape of the holes the measurement was taken from the center of the holes and not from their periphery. In order to ascertain the distribution of stress in the parent metal, 39 holes were drilled in each row with 18 distances on either side of the weld's center line.

The distance between these holes was to be determined with the aid of the Abramson gage, and the instrument had, therefore, to be adjusted for taking such measurements. To the bars of a horseshoe-shaped clamp were soldered balls, as shown in Fig. 5, which were intended to rest in the holes as per Fig. 6. The construction of the instrument is further illustrated in Fig. 7.

When the conical holes were drilled in the test-pieces there naturally arose burrs in the holes or small metal filings adhering to the sides. Each hole was, therefore, treated with a ball of the same diameter as the 0.08 inch balls in the measuring apparatus. This auxiliary ball was laid in the hole and a 44-lb. weight was then placed on it. This produced a ring around the hole inside, in which all burrs and filings were impressed into the metal, so that the surface of the ring became quite smooth.

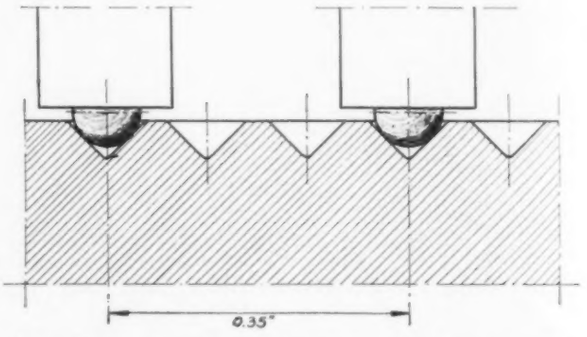


Fig. 6—The Positions of the Measuring Balls in the Measuring Holes

The greatest care had to be taken when the measurements were being made to see that each of the holes was perfectly clean. They were, therefore, washed with gasoline, and, besides the premises were kept as free from dust as possible. At the same time care was taken to ensure that the temperature of the premises was constant while the measuring was going on.

Each L along which the distance change was to be ascertained was, as we have mentioned, 0.12 inch long. The distance between the balls in the gage was, however, 0.35 inch (Fig. 6). This means that whenever a measurement is taken the gage will span three of these 0.12 inch L distances. In each row, that is to say, a measurement is taken between the first and fourth hole, between the second and fifth, between the third and sixth, and so on. In view of the fact that the measuring distances partially overlapped not only was it easy to check the measurements but it was also possible to calculate the variation along each 0.12 inch L distance. If the error of measurement along a 0.35 inch L distance was $\pm$ 0.3 μ,

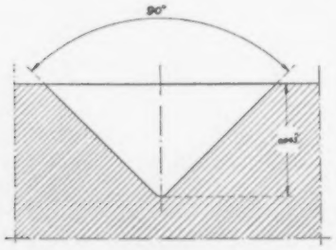


Fig. 4—Shape of the Measuring Holes

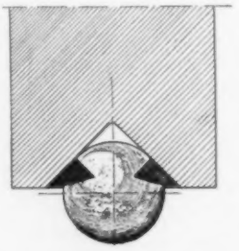


Fig. 5—How the Measuring Balls Are Attached

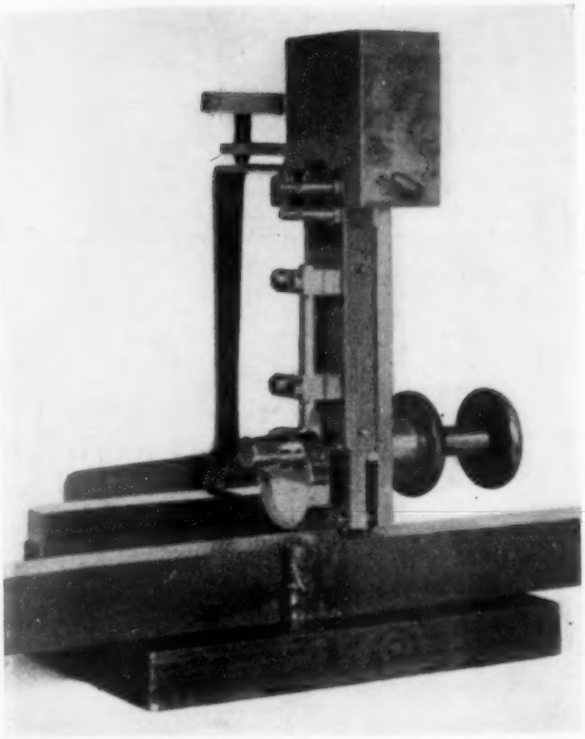


Fig. 7—The Instrument Adjusted for Taking Measurements

then along each 0.12 inch L distance it would be one-third thereof, or $\pm$ 0.1 μ. However, the absolute distance between the points was a matter of no consequence. It was only necessary to know to what extent it changed longitudinally upon the cut being made. For this reason it was best to compare the extent to which the distance diverged from a certain given distance first in the one case and then in the other. This given distance should be represented by a similarly marked-out 0.35 inch L distance, i. e. by two conical holes at a distance from one another = the distance between every fourth hole in the test piece. A standard gage was, therefore, made out of a bar of iron with a polished surface, in which were drilled the conical holes, these being treated in the same way as the holes in the test piece.

The scale of the measuring instrument was graduated in thousandths of millimeters. This scale, however, required a correction curve, which was constructed with the aid of Johansson gage blocks.

The test piece having been measured, it was to be released from turning shrink stresses by means of cuts. The procedure was as follows: the piece was placed in a filing machine, in which a thin bow-saw-blade was used for making the cut. Slots 0.04 inch deep were sawn alternately on either side until only a tongue 0.16 inch thick in the middle held the weld on one part of the plate. The 0.04 inch broad cuts were sawn, as shown in Fig. 8, on the edge of the weld 0.59 inch from the center of the weld right through four conical holes. While being sawn the test piece was handled with extreme care so that no disturbances of the stresses should be caused by jolts and so as not to bend the piece.

The turning bending shrink stresses having thus been released in the test piece, the distances between the holes were again measured in the same way as before, and the divergence between them and the standard gage was recorded. This gave the distance changes which the piece had undergone when being sawn, and it was thus possible to work out the stresses. By marking off the distance changes in each 0.35 inch L distance as ordinates in the diagrams in the middle of each L distance with tension stress as negative ordinate and compressive stress as positive ordinate, and joining up the points thus arrived at, the stress diagrams were obtained which are reproduced in Figs. 8 and 9. If the ordinates of these curves in the holes are marked off horizontally with tension stress on the left and compressive stress on the right, we obtain the curves shown in Figs. 10 and 11. In Figs. 8–11 the distribution of the stress is indicated around the cut by dotted lines, as the measuring holes in the middle of the cut made by the saw could not be used and consequently the stress is not determined with the same degree of certainty there as it is in the other places.

The results of the measurements could be checked owing to the fact that we know that the sum of all distance changes in respect of each horizontal row of holes is equal to the similar sum in respect of every other row of holes.

It will be seen from the figures that the turning bending

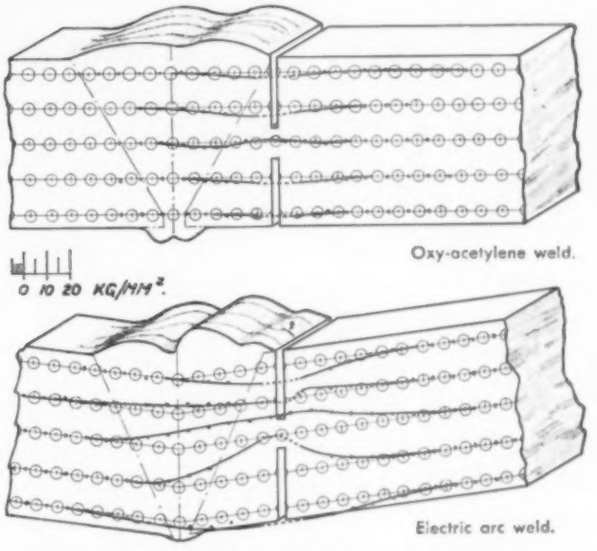


Fig. 8—Turning Bending Shrink Stresses in a Single V Gap Drawn at Right Angles to the Direction of Stress 0.116 Inch = 10,000 Lb./In.²

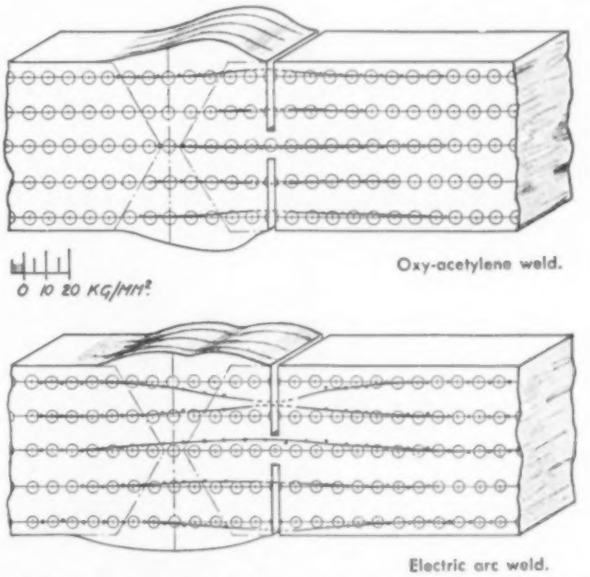


Fig. 9—Turning Bending Shrink Stresses in a Double V Gap Drawn at Right Angles to the Direction of Stress 0.116 Inch = 10,000 Lb./In.²

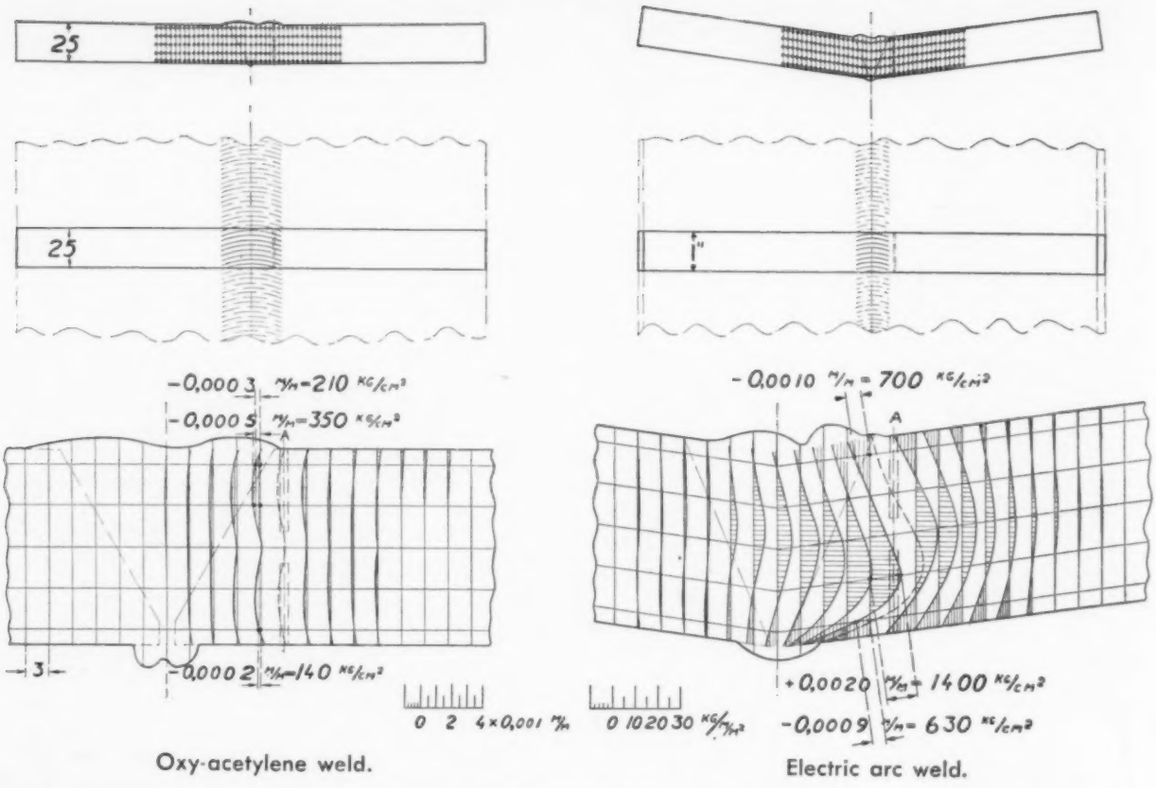


Fig. 10—Turning Bending Shrink Stresses in a V Gap Drawn Parallel to the Direction of Stress 0.090 Inch = 10,000 Lb./In.²

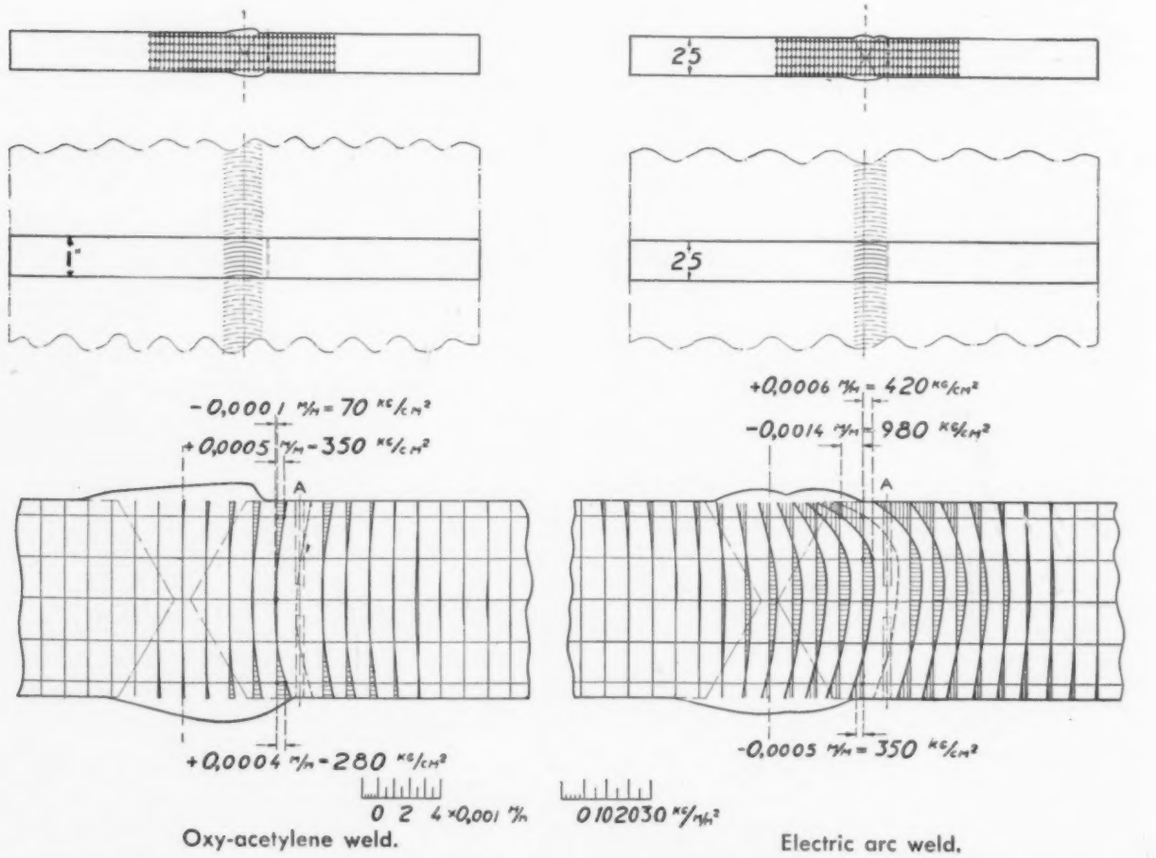
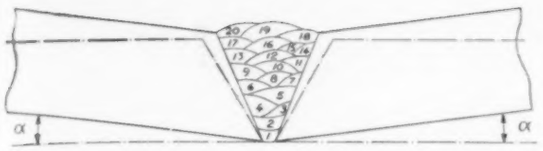
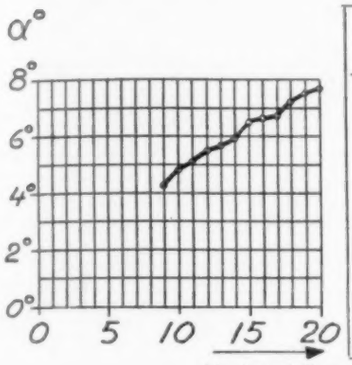


Fig. 11—Turning Bending Shrink Stresses in a Double V Gap Drawn Parallel tothe Direction of Stress 0.090 Inch = 10,000 Lb./In.²





Number of welded Runs	α°
9	4,2
10	4,8
11	5,1
12	5,5
13	5,7
14	5,9
15	6,5
16	6,6
17	6,7
18	7,2
19	7,5
20	7,7

Dimensions of Arc Welded Plate = 300×300×25 mm.

Fig. 12—Turning Shrinkage of Arc Welding of 25 Mm. Plate

shrink stresses are very insignificant in the oxyacetylene weld when compared with those in the arc weld, and, in so far as they can be read off, they appear to be of an opposite character.

In the arc welds we find a pronounced tension stress at the surfaces of the plate and a compressive stress between them, whereas in the oxyacetylene welds there are only slight compressive stresses at the surfaces and a tension stress in the middle. The probable cause of this is discussed in the aforementioned number of the *AGA-Journal*.

All specimens were welded without restraint. The oxyacetylene weld was made with a wedge to maintain spacing. The arc weld was forked to maintain a spacing of 0.12 inch. A torch consuming 71 liters acetylene per hour was used for oxyacetylene welding. The arc welds were made with Stabilend No. 6 electrodes, 200 amps. The total scarf angle was 60°. The V joint (arc weld) was filled with 20 runs, the angular distortion being measured after every run after nine runs had been deposited, Fig. 12. The X joint (arc weld) was made in 16 layers, alternately on either side of the joint.

The high degree of accuracy attained in the measurements described above would appear to be not only quite uncommon for workshop measurements but even generally within the field of metrology.

During the first attempts to take these measurements it was considered impossible in the opinion of experts to arrive at the degree of accuracy indicated by 0.1 μ with the aid of mechanical gages. Indeed, van Steewen declared that the greatest degree of accuracy attainable by purely mechanical gages is 1–3 μ. Quite recently, elastic stresses have been measured on the surface by allowing X-rays to be reflected against it. According to "IVA," No. 1, 1937 it is possible by that means to measure stresses with an accuracy of 2800 lb./in.^{2}, which shows that even that refined method is inferior to our method of measuring described above, which gives a degree of accuracy of 1000 lb./in.^{2}

Nitrogen in Welds

THE following discussion of the review of literature on the Effect of Nitrogen on the Welding of Steel has been forwarded by Dr. L. Reeve, of the Appleby-Frodingham Steel Co. Ltd., Scunthorpe, England.

The classical work of Tschischewsky (Journal of the Iron & Steel Institute 1915 No. II p. 47) which has been previously quoted in several papers, including my own to the Welding Symposium, deserved to be quoted. As this is one of the very few papers giving any information on the influence of nitrogen from 0 to 0.15% on the mechanical properties of steel it should have been quoted, although I agree it needs confirmation.

Hoyt's most recent paper on fractional vacuum fusion (*A.I.M.M.E. Tech.* Publication 821 Oct. 1937) amplifies my own work on different types of nitride and their influence on the formation of nitride needles, and could have been quoted in the section on the influence of various elements (p. 15.)

Another point which I have queried the statement that "increase in length of arc increases nitrogen pick up *slightly*."

It is true that the quantitative experiments quoted indicate that the increase is not very great proportionally, but these are entirely tests on bare wire welds.

The effect is much more striking with covered electrode welds, and I am surprised that apparently there is no quantitative information available for these.

The following results we have obtained here with Class A covered electrode may, therefore, be of interest:

No.	Conditions	Nitrogen, %
1	140–150 amps. – 1/8-inch arc	0.042
2	140–150 amps. – 3/8-inch arc	0.084
3	160–170 amps. – 1/8-inch arc	0.035
4	160–170 amps. – 3/8-inch arc	0.078

It will be noted that the nitrogen content is approximately doubled by increasing the arc length from 1/8 to 3/8 inch. Increased current tends to reduce the nitrogen slightly which confirms the review.

WELDING VANADIUM STEELS

A Review of the Literature to July 1, 1937

By W. SPRARAGEN* and G. E. CLAUSSEN†

This report is prepared under the auspices of

THE LITERATURE DIVISION OF THE ENGINEERING FOUNDATION
WELDING RESEARCH COMMITTEE

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Summary

WELDING CARBON-VANADIUM STEELS

Oxyacetylene Welding

The rotating bend fatigue strength (40×10^6 cycles) of unmachined oxyacetylene butt welds in plain carbon steel aircraft tubing 1 inch diameter, $^1/_{16}$-inch wall, made with a rod containing 0.25 C, 0.43 Mn, 0.17 Si, 0.15 V was 14,000 lb./in.^{2} The tensile strength was 57,500 lb./in.^{2}, failure occurring 1 inch outside the weld.

Arc Welding

One investigator believes that boiler plate containing 0.20 V should be normalized at 830° C. after arc welding. Another states that heat treatment after welding with flux coated electrodes is superfluous if the carbon content is below 0.18% with about 0.10 V.

Water Gas Welding

A steel containing 0.15 C, 0.65 Mn, 0.20 V is used in Europe for hammer welded and fusion welded boilers and pressure vessels of relatively thin section. Water gas welds have been produced in a steel 1.26 inches thick containing 0.19 C, 0.00 Si, 0.47 Mn, 0.19 V, 0.028 S, 0.015 P having tensile strengths equal to 85% of the plate material for a range of temperature from 20 to 500° C., but with poor tensile ductility. However, the notch impact values were good.

Recovery

It has been found that recovery of vanadium from a water glass coating containing ferrovanadium, ferromanganese and graphite varied from 19 to 72%. The percentage recovered increased rapidly as the manganese content of the coating was increased and to some extent also as the vanadium content of the coating was increased. The recovery of carbon increased as the recovery of vanadium increased.

WELDING MANGANESE-VANADIUM STEELS

All-weld-metal tensile specimens and Charpy impact specimens from butt welds in machined plates, $^1/_2$ inch thick containing 0.16 C, 1.16 Mn, 0.16 Si, 0.19 V, 0.11 Cr, 0.12 Ni made with a covered electrode ($^5/_{16}$ inch diameter, 450 amps.) of the same composition had tensile strength and ductility after being heat treated at 650° C. for 2 hours equal to base metal. The notch impact values, however, were only $^2/_3$ that of the base metal for a range of temperatures from room temperature to −46° C. At −46° C. the Charpy value of the weld was 31 ft.-lb., the same as unwelded base metal. The heat affected zone was 21 to 28 ft.-lb. Charpy at −46° C. The Committee on Low-Alloy Steels decided that steels containing 0.14–0.20 C, 1.32–1.57 Mn, 0.02–0.24 Si, 0.10–0.18 V were moderately air hardening under average welding conditions.

WELDING NICKEL-VANADIUM STEELS

Cast nickel-vanadium steel (1.50 Ni, 0.10 V) need not be stress relieved after welding, if the carbon content is below 0.25%. With higher carbon the casting must be preheated and stress relieved.

Welding Vanadium Steels

INTRODUCTION

A good source of information on vanadium steels is the series of articles by Norris and Strauss (Metals Handbook, 1936 edition, 455–470). Vanadium (about 0.18%) is added to steel for the following reasons:

1. To refine the primary grain size in the ingot.
2. To secure steel with uniformly fine grain size even after overheating (Widmannstätten structure is seldom found in vanadium steels.)

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3. To increase the strength without loss of ductility, especially at elevated temperatures.

For welding purposes the vanadium content of steel is generally 0.10–0.12%.

Vanadium is usually added in the ladle as 40% ferrovanadium. Since the steel is deoxidized with silicon before the ferrovanadium is added, the recovery of vanadium is high although, like chromium, a little is lost by oxidation. In acid slags vanadium is a weaker reducing agent than manganese, but in basic slags the reverse is true.

Vanadium carbide, V_4C_3, is certainly formed in steels with 1.00 V, 0.25 C and higher, probably also in steels with as little as 0.10 V. It may be the carbide or some other inoculating compound, such as oxide or nitride, that accounts for the unusually fine grain size of vanadium steels, and for their high strength at elevated temperatures. If the vanadium in the steel is combined as carbide or other compound not taken into solid solution during the heating cycle, vanadium does not promote deep hardening.

If the heating cycle has been such that the vanadium compound is dissolved the solid solution of vanadium and carbon in the austenite promotes deep hardening.

The literature on the welding of vanadium steels is meager but provides no grounds for believing that the effects of vanadium in welding are different from the effects in steel making.

WELDING CARBON-VANADIUM STEELS

Oxyacetylene Welding

According to the Vanadium Corporation,[1] an uncoated rod for obtaining strong, fine grained oxyacetylene welds contains 0.12 C, 0.15 Si, 0.35 Mn, 0.15 V. A similar rod[2] (0.10 C, 0.24 Mn, 0.21 Si, 0.17 V) was recommended in 1916 and was closely akin to S. W. Miller's[3] rod, which contained 0.16 C, 0.19 Mn, 0.11 Si, 0.19 V. The International Railway Congress Association[4] believe that gas welding is safe practice for low-carbon vanadium steel but that heat treatment is essential. The hysteresis loss of oxyacetylene deposits made with a rod containing 0.12 C, 0.16 Si, 0.94 Mn, 0.19 V was found by Hess and Ringer[5] to be relatively high (over 0.04 watt sec./lb./cycle at 6000 gauss) on account of the high manganese content. R. R. Moore[6] found that the rotating bend fatigue strength of unmachined oxyacetylene butt welds in plain carbon steel aircraft tubing 1 inch diameter, 1/16 inch wall, made with a rod containing 0.25 C, 0.43 Mn, 0.17 Si, 0.15 V was 14,000 lb./in.^{2} The tensile strength was 57,500 lb./in.^{2}, failure occurring 1 inch outside the weld. Moore's fatigue results doubtless were influenced to an important extent by the fact that the welds were not machined.

In oxy-illuminating gas welding low-carbon steel plates 2 inches wide, 1/8 and 1/4 inch thick, Lurie[7] found that a rod containing 0.10 C, 0.08 Si, 0.23 Mn, 0.88 V, which is a most uncommon composition at present, gave excessive slag and a lumpy flow. Machined butt welds 1/4 x 1 3/4 inches had a tensile strength of 38,000 to 43,000 lb./in.^{2} (about 65% of base metal) and an elongation of 3 to 5% in 1 1/2 inches.

Arc Welding

Aside from general statements, there is no information about the arc welding of plain vanadium steels. The Lincoln Handbook[8] states that vanadium seems to have a beneficial effect in reducing porosity in silicon-killed welds. Viall[9] thought vanadium steels were extremely easy to weld, and Kautny[10] recommended vanadium steel electrodes for high strength welds. According to Herzog,[11] vanadium improves the welding qualities of some low-alloy steels. Schimpke and Horn[12] believe that boiler plate containing 0.20 V should be normalized at 830° C. after arc welding. In the presence of less than 0.18 C, according to A. W. Demmler (private communication, May 1938), welds made with flux coated electrodes in steel of the sort mentioned by Schimpke and Horn require no heat treatment, because air hardening and loss of ductility are slight. Karsten[13] had a high opinion of the welding qualities of all vanadium steels, but he believed that the filler rod should have the same composition as base metal. A filler rod with 0.95 Mo was recommended as being even better than filler rods of base metal.

Water Gas Welding

The Vanadium Corporation[1] state that a steel containing 0.15 C, 0.65 Mn, 0.20 V is used in Europe for hammer welded and fusion welded boilers and pressure vessels of relatively thin section. Tests on automatic water gas welds in a steel 1.26 inches thick containing 0.19 C, 0.00 Si, 0.47 Mn, 0.19 V, 0.028 S, 0.015 S have been made by Prömper and Pohl,[14] Table 1. The high temperature tensile tests were made in paraffin up to 250° C. and in molten salt at higher temperatures. The rate of application of load was 70 lb./in.^{2} per sec. The welded tensile bars were straightened at a red heat and were normalized. The notch impact specimens were not straightened, but were normalized. The notch impact specimens were 1.18 x plate thickness x 6 inches long with notch 0.16 inch diameter in the weld. The axis of the unwelded tensile specimens was in the direction of rolling. Fractures occurred in the weld. The tensile ductility of the welds was particularly low. In other respects, the welds were not greatly inferior to base metal. The absence of silicon in the steel is contrary to practice in this country for steel of the type tested by Prömper and Pohl.

Table 1—Mechanical Properties of Water Gas Welded Carbon-Vanadium Steel. Prömper and Pohl[14]

Temperature of Test, ° C.	Yield Strength, Lb./In.^{2}		Tensile Strength, Lb./In.^{2}		Elongation, % in 8 Inches		Notch Impact Value, Mkg./Cm.^{2}	
	Unwelded	Welded	Unwelded	Welded	Unwelded	Welded	Unwelded	Welded
20	42,800	40,000	58,000	50,700	26.2	8.2	9.3	8.3
100	40,000	34,700	58,200	51,000	20.5	3.5	13.5	12.55
200	38,800	37,000	60,500	53,000	18.5	4.7	12.35	12.15
250	35,000	34,300	61,500	62,700	18.0	3.0	11.6	11.5
300	31,600	30,700	56,800	49,800	22.8	4.0	11.4	12.35
400	30,700	30,300	50,300	42,200	38.1	14.5	9.85	5.55
500	28,500	27,800	37,900	35,400	41.5	9.5	7.9	5.75

Resistance Welding

Schröder[15] mentioned that vanadium cast steel is suited to resistance welding into large assemblies.

Flame Cutting

Low-carbon vanadium steels should be heat treated after flame cutting, in the opinion of the International Railway Congress Association.[4] With less than 0.18 C and about 0.10 V, according to A. W. Demmler (private communication, May 1938) there is no need for heat treatment after flame cutting. Janiszewski[16] briefly describes the flame cutting of carbon-vanadium tool steel dies and their welding to machine steel in making composite dies.

Recovery

According to Strauss,[17] the average loss of vanadium from ten different electrodes with three different coat-

ings was 0.045%. The highest vanadium content was 0.11%. Using methods described in an earlier review (see review of literature on Welding Nickel Steels, Table 24), Losana and Jarach,[18] Table 2, found that recovery of vanadium from a waterglass coating containing ferrovanadium, ferromanganese and graphite increased from 19 to 72% as the manganese content of the coating increased from almost nil to 15%.

The percentage recovered increased rapidly as the manganese content of the coating was increased and to some extent also as the vanadium content of the coating was increased. The recovery of carbon increased as the recovery of vanadium increased. The deposit from the covered electrode (0.23 C, 0.72 Mn, 0.05 Si, 0.10 V) used by Csilléry and Péter[19] contained 0.08 C, 0.18 Mn, 0.11 Si, the presence of vanadium in the deposit not being reported. A weld made with a bare electrode 0.16 inch diameter containing 0.50 C, 0.20 Si, 1.50 Mn, 0.60 V in a rail containing 0.60 C, 0.20 Si, 1.00 Mn, 0.30 V, according to Csilléry and Péter had 0.20 C, 0.13 Si, 0.56 Mn, 0.30 V. Both Holmberg[20] and Chapman[21] refer to the poor recovery of vanadium in fusion welding.

Table 2—Recovery of Vanadium from Coated Mild Steel Electrodes. Losana and Jarach[18]

N°	(Mn)	(Si)	(C)	(V)	$(V)^1$	[Mn]	[C]	[V]	$[V]/(V)^1$
1	0.38	2.10	2.32	3.86	1.5	0.01	0.04	0.28	0.19
2	0.42	2.02	2.14	7.32	2.9	0.03	0.16	0.84	0.29
3	0.32	2.24	2.18	15.18	6.0	0.05	0.43	2.03	0.34
4	7.21	2.12	2.08	3.70	1.5	0.27	0.17	0.86	0.57
5	7.16	1.98	2.24	7.02	2.8	0.39	0.25	1.78	0.64
6	7.02	2.20	2.31	13.84	5.5	0.66	0.58	3.52	0.64
7	14.86	1.9	2.25	3.68	1.5	0.77	0.21	0.99	0.66
8	15.24	2.13	2.10	6.92	2.7	0.98	0.33	1.89	0.70
9	15.32	2.08	2.18	14.64	5.8	1.34	0.69	4.18	0.72

( ) = weight % constituent in coating
[ ] = weight % constituent in deposit
$(V)^1$ = percentage of vanadium in electrode calculated on basis of core rod of electrode

$[V]/(V)^1$ = approximate recovery of V.

The ferrovanadium contained 52.46 V, 0.98 Mn, 0.44 Si, 0.87 C, 0.054 S, 0.013 P.

WELDING MANGANESE-VANADIUM STEELS

All-weld-metal tensile specimens (0.505 inch diameter) and Charpy impact specimens were prepared by Hopkins[22] from butt welds in machined plates, 1/2 inch thick containing 0.16 C, 1.16 Mn, 0.16 Si, 0.19 V, 0.11 Cr, 0.12 Ni made with a covered electrode (5/16 inch diameter, 450 amps.) of the same composition, Table 3. All specimens were heated 2 or 36 hr. at 650° C. and furnace cooled. The weld-metal contained 0.10 C, 0.70 Mn, 0.35 Si, 0.25 V, 0.10 Cr. Extending the time of treatment at 650° C. from 2 to 36 hr. had no effect on the hardness and tensile properties of the weld, but improved the notch impact value of the heat affected zone. The notch impact value was not significantly lower at −46° C. than at +21° C. Weld, heat affected zone, and base metal had a uniformly fine grain size.

Typical tensile properties of welds in a steel containing 0.19 C, 0.25 Si, 1.62 Mn, 0.17 V made with a shielded-arc carbon-molybdenum electrode, according to Jennings,[23] Table 4, are slightly lower than unwelded base metal. Jennings recommended the use of shielded arc electrodes of the C-Mo or Cr-V types. Preheating was not considered necessary unless the sections were heavy, nor was stress annealing required ordinarily. On the other hand, the Committee on Low-Alloy steels[24] decided that steels containing 0.14–0.20 C, 1.32–1.57 Mn, 0.02–0.24 Si, 0.10–0.18 V were moderately air hardening under average welding conditions. The difficulty experienced by Watertown Arsenal (private communication, May 1938) in welding Mn-V steels of the type studied by Hopkins and Jennings was with segregation and laminations. Otherwise there was no difficulty in obtaining 60,000–70,000 lb./in.² yield strength (dividers method), 80,000–85,000 lb./in.² tensile strength, 24–30% elongation in 1 inch in butt welds in 3/4-inch plate made with covered low carbon electrodes. According to Vanadium Corporation,[1] uncoated rods containing 0.15 C, 0.20 Si, 1.00 Mn, 0.15 V deposit fine grained oxyacetylene weld-metal having a yields trength of 60,500 to 69,000 lb./in.², tensile strength = 72,000 to 78,500 lb./in.², 24.0 to 28.5% elongation in 2 inches. A. W. Demmler (private communication, May 1938) states that many thousand tons of plate and structural shape containing 0.18 C max., 1.45 Mn max., 0.15–0.30 Si, 0.80–0.14 V have been made particularly for application to welded structures which in many instances could not be heat treated after welding. A steel containing 0.18 C, 0.99–1.18 Mn, 0.05 Cr, 0.07 V, 0.16 Cu tested by the Navy Department (private communication, May 1938) in a restricted Tee weld bend jig was unsatisfactory in the as-rolled condition but was satisfactory after being normalized at 900° C. for 1 hr. Single V butt welds made with a covered medium steel electrode in 3/8-inch plate with 1/16-inch reenforcement on each side had a tensile strength of 93,400 lb./in.² unmachined, 82,000

Table 4—Tensile Properties of Arc Welded Mn-V Steel. Jennings[23]

	Yield Strength, Lb./In.²	Tensile Strength, Lb./In.²	Elongation, % in 2 Inches	Reduction of Area, %
Unwelded Base Metal	70,000 to 80,000	100,000 to 110,000	20 to 30	40 to 50
Weld	66,000	95,000	22	35

Table 3—Mechanical Properties of Arc Welded Mn-V Steel. Hopkins[22]

Time of Treatment at 650° C.	Yield Strength, Lb./In.²		Tensile Strength, Lb./In.²		Elongation, % in 2 Inches		Reduction of Area, %		Maximum Brinell Hardness		
	Base Metal	All-Weld-Metal	Base Metal	All-Weld-Metal	Base Metal	All-Weld-Metal	Base Metal	All-Weld-Metal	Weld	Heat Affected Zone	Base Metal
2 hr.	50,000	46,550	68,000	64,150	30.5	34.0	53.3	65.4	123	128	125
36 hr.	46,600	46,700	63,500	63,750	34.0	36.0	68.0	67.9	125	123	120

Time of Treatment at 650° C.	Charpy Impact Value								
	+ 21° C.			−32° C.			−46° C.		
	Weld	Heat Affected Zone	Base Metal	Weld	Heat Affected Zone	Base Metal	Weld	Heat Affected Zone	Base Metal
2 hr.	38.4	22.8	35.4	34.0	19.9	37.1	30.7	21.1	31.4
36 hr.	39.8	29.1	38.0	36.7	27.5	24.9	31.0	27.8	25.5

lb./in.^{2} machined. The average tensile strength of base metal was 92,500 lb./in.^{2}

Unheat treated butt welds in plates $^3/_8$, $^3/_4$ and $1^1/_2$ inches thick containing 0.17 C, 1.38 Mn, 0.10 V made with several different electrodes never exceeded 232 Brinell in weld or heat affected zone, according to A. W. Demmler (private communication, June 1938). The highest hardness (232 Brinell) was observed in the heat affected zone. The maximum Brinell hardness $^1/_2$ inch beyond the heat affected zone revealed by etching was 195. Unwelded base metal was 178–185 Brinell. Regardless of type of electrode the Izod value was 42 to 59 ft.-lb. for all-weld-metal, and 50 to 120 ft.-lb. for notches cut precisely in the the junction zone. The weld-metal having the lowest Izod value had a tensile strength of 98,700 lb./in.^{2} The lowest Izod value in the heat affected zone was secured with an unalloyed electrode.

Three bare electrodes, 0.16 inch diameter, were used by Csilléry and Péter,[25] Table 5, to weld a rail containing 0.60 C, 1.00 Mn, 0.30 V, 0.20 Si. The tensile specimens were 0.39 inch diameter. The cross section of fracture of the notch impact specimen was 0.55 inch square, with a notch 0.28 inch deep, 0.16 inch diameter. Hardness was measured with a Rockwell machine, 0.10-inch ball.

Table 5—Mechanical Properties of Arc-Welded Rail. Csilléry and Péter[25]

Weld made with	Tensile Strength, Lb./In.^{2}	Elongation %*	Reduction of Area, %	Notch Impact Value, Mkg./Cm.^{2}	Brinell 1	Brinell 2	Hardness Weld
Electrode A	46,500	9.6	12.6	1.5	220	220	104
Electrode F	96,500	15.3	11.5	9.5	275	250	226
Electrodes F and A	89,000	13.8	10.3	12.8	230	232	85 to 102
Electrodes E and D	53,000	16.0	13.6	2.2	223	213	222 to 231
Unwelded Rail	133,000–157,000	9.4–17	14.8–45	1.88–2.27		230 to 308	

*-% in 5 diameters or in length of weld.
1 = junction of base metal with heat affected zone.
2 = junction of weld metal with heat affected zone.

	C	Mn	Si	V	
Electrode A	0.10	0.50	0.20	..	
Electrode D	0.12	0.40	trace	..	
Electrode F	0.50	1.50	0.20	0.60	
Deposited Metal	0.20	0.58	0.13	0.30	(with electrode F)

Best results were secured with electrode F. With this electrode the welds had about the same grain size as the unwelded rail. Since the welds deposited by the other electrodes were comparatively coarse grained, Csilléry and Péter concluded that vanadium refined the grain structure. Using the Spindel apparatus, 11 lb. load, 29 cycles per minute, total of 200 revolutions, Csilléry and Péter[25] found that the wear resistances of rail, weld and heat affected zone were in the ratio: 15.2, 22.0, 40, respectively, the unwelded rail showing the least wear.

WELDING MOLYBDENUM-VANADIUM STEELS

In the discussion of Warner's[26] research on the fillet welding of SAE 2320 steel to a cast steel $1^1/_4$ inch thick containing 0.425 C, 0.71 Mn, 0.29 Si, 0.286 Mo, 0.10 V with unalloyed low-carbon electrode (see review of literature on Welding Nickel Steels, section on Hardness, Tables 18 and 19) it was pointed out that preheating to 200° C. was sufficient to prevent cracks and the appearance of martensite in the heat affected zone of the casting. If the preheated welded joint was heated at 300° C. for 16 hr. there was no change in the structure; neither preheat nor post heat affected the structure (sorbitic) of the base metal. In multi-layer welds without preheat there was coarse martensite in the heat affected zone adjacent to the last layer deposited. The structure of the heat affected zones of the other layers was sorbitic. If the last layer deposited was kept from approaching closer than 0.01 to 0.04 inch from base metal, it was believed that the presence of martensite in base metal could be prevented. A similar steel (0.40 C, 0.70 Mn, 0.15 Si, 0.17 V, 0.25 Mo) was recommended by the Vanadium Corporation for excellent welding qualities for assemblies heat treated to moderately high hardness after welding.

Preheating to over 200° C. (over 400° F.) was found by N. L. Mochel (private communication, April 1938) to be quite necessary in fabricating gear wheels, 36 and 96 inches diameter, with rims made of steel containing 0.29 C, 0.69 Mn, 0.22 Si, 0.34 Mo, 0.20 V, 0.035 P, 0.036 S. An electrode containing 0.50 Mo was used. If the temperature was not maintained over 200° C. during welding followed by stress relieving promptly at 650° C. (1200° F.), there was excessive hardening near the welds and cracks occurred.

A good filler rod for building up worn tools, according to Vincent,[27] contained 0.68 C, 0.25 Mn, 0.25 Si, 1.25 V, 0.95 Mo, 0.35 Cr. Lathe and planer tests on tools built up with this rod were fairly satisfactory (full details of these tests are furnished in the original article). Deposits on a plate $^1/_4$ inch thick made with a bare electrode $^5/_{32}$ inch diameter, 110–160 amps. or with a neutral oxyacetylene flame, were 575 to 667 Brinnell. An oxidizing flame produced porous welds.

WELDING NICKEL-VANADIUM STEELS

Cast nickel-vanadium steels ($1^1/_2$ Ni, 0.10 V) need not be stress relieved after welding, according to Armstrong,[28] if the carbon content is below 0.25%. With higher carbon the casting must be preheated and stress relieved. The hysteresis loss of oxyacetylene weld deposits made with a rod containing 0.11 C, 0.22 Si, 0.58 Mn, 0.22 V, 2.27 Ni, 0.15 Cr was rather high (over 0.05-watt sec./lb./cycle at 6000 gauss), according to Hess and Ringer.[5] The manganese content was believed to be too high for low hysteresis loss.

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SUGGESTED RESEARCH PROBLEMS

1. Mechanical properties (static tensile, bend, notch and tensile impact) of all-weld-metal containing different carbon and vanadium contents with perhaps additions of manganese, nickel and molybdenum prepared by oxyacetylene and metal arc processes. The composition (0.18 C max., 1.45 Mn max., 0.15–0.30 Si, 0.08–0.14 V) suggested in Metals Handbook, 1936 Edition, p. 463, is a particularly timely one to study.

2. How does the grain size (dendrites) of single beads of weld-metal containing different proportions of carbon and vanadium deposited by arc and oxyacetylene processes compare with similar deposits containing no vanadium? What types of microstructure are observed? Has the deposition of another layer any unusual effect on the first layer?

3. Does the grain structure of spot and flash resistance welds in carbon-vanadium or manganese-vanadium steels differ from similar welds in steels free from vanadium? Does the vanadium content require alterations in machine settings?

4. Arc characteristics using iron or steel electrodes containing different proportions of vanadium, either as alloy in the rod or as compound in the coating.

5. Hardness surveys of the heat affected zone of carbon-vanadium, manganese-vanadium and nickel-vanadium steels with carbon contents from 0.10 to 0.30% after a bead of weld-metal has been deposited on the surface. Effect of thickness and other dimensions of plates and of speed of travel and heat input of the source of heat.

TESTS OF WELDED FRAMEWORKS*

By DR. G. VON KAZINCZY

THE behavior of a welded or riveted structure beyond the elastic limit often suggests modifications of design to the engineer whether or not the design is based on elastic strains only (Hooke's Law) or on plastic or permanent strains as well. A welded, statically indeterminate framework, Fig. 1, was tested in tension to determine its plastic behavior. The mild steel framework consists of two statically determinate parts: the vertical tension bar and the remaining framework. The vertical bar was designed to yield at 64% of the yield load for the remainder of the framework. Upon being unloaded after having been stressed beyond the yield point the vertical bar acts as a column and tends to assume an S shape, Fig. 1.

The load-extension diagram, Fig. 1 is based on the total motion of the gussets in a vertical direction, measured with an accuracy of 0.0004 inch. Agreement with calculation was good but three disturbing observations were made: (1) the first bend in the load-extension curve, which signifies yield of the vertical bar, occurred at too high a load, (2) the first flow figures appeared at a unexpectedly low load, and (3) the local stresses created by the stiffness of the gussets did not give rise to flow figures.

It was believed that the first observation was related to shrinkage stresses set up by welding. The effects of shrinkage stresses are indicated in Fig. 2. There is no effect on the ultimate load, but the permanent deformations are increased if the shrinkage stress in the vertical bar is tension, or decreased if compression.

The shrinkage stresses in the vertical bar were measured by means of Huggenberger extensometers mounted on opposite sides during welding of the second end. The shrinkage stress after cooling was 9900 lb./in.^{2} Since the yield strength of the steel was 31,200 lb./in.^{2} and yielding occurred in the vertical bar at 23,300 lb./in.^{2}, the difference, 7900 lb./in.^{2}, is in good agreement with the measured shrinkage stresses. Yielding occurred in a few small regions of the vertical bar where flow figures appeared. The remainder of the bar, 97% of the length,

* Abstract of an article published as Versuche mit innerlich statisch unbestimmten Fachwerken, in *Bauingenieur*, **19**, (15/16) pp. 236–245, April 15, 1.38.

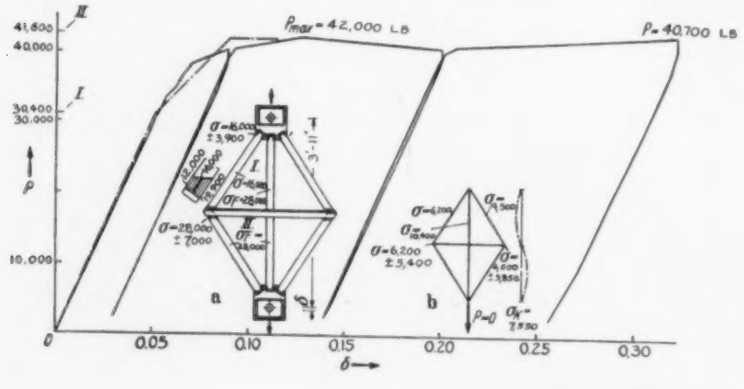

Fig. 1—Load-Extension Diagram of a Welded Statically Indeterminate Framework

— · — · — · calculated
———— observed

a) calculated stresses (σ in lb./in.^{2}) near and remote from the welds
I—at the limit of complete elasticity
II—at the maximum load (complete yield)
The vertical and diagonal bars are rectangular in cross section, 0.32 × 1.77 inches. The horizontal compression bar consists of two angles 0.32 inch thick, 1.58 inches leg
P = load, lb.
δ = extension of framework in direction of load inches

(*b*) calculated stresses in members after the external load has been raised to 41,600 and released. Left-hand side shows stresses in diagonal bar remote from and near welds and in tension bar, if the latter did not fail by buckling. If the tension bar fails by buckling at a stress (σ_K) of 7600 lb./in.^{2} (L/r = 130), the stresses in the diagonal bar are lower as shown in the right-hand side of (*b*)

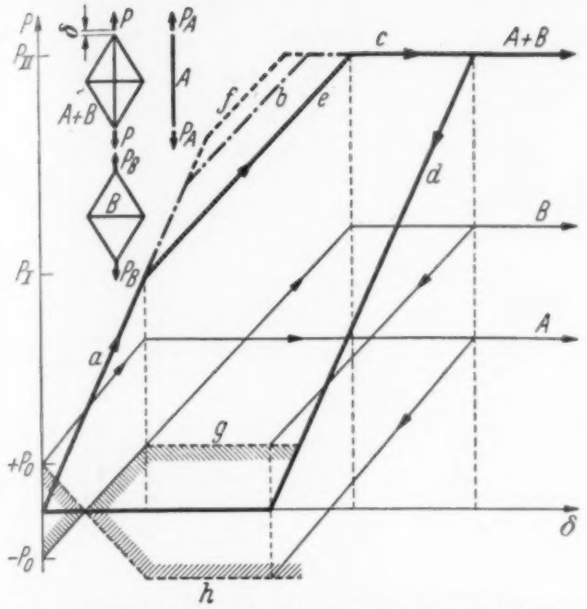

Fig. 2—Calculated Load-Extension Diagram for an Ideal Statically Indeterminate Framework Having Initial Shrinkage Stresses Due to Welding, $+P_0$ and $-P_0$

The framework consists of vertical tension bar A and the remainder B, both of which are statically determinate. Lines A and B are the load-extension diagrams of the separate parts A and B. Line b applies if the shrinkage stress is absent. If bar A contains initial compressive shrinkage stress ($-P_0$) instead of initial tension, line f applies. Lines g and h are the loads in A and B after external load is removed. Line d shows the permanent elongation on unloading

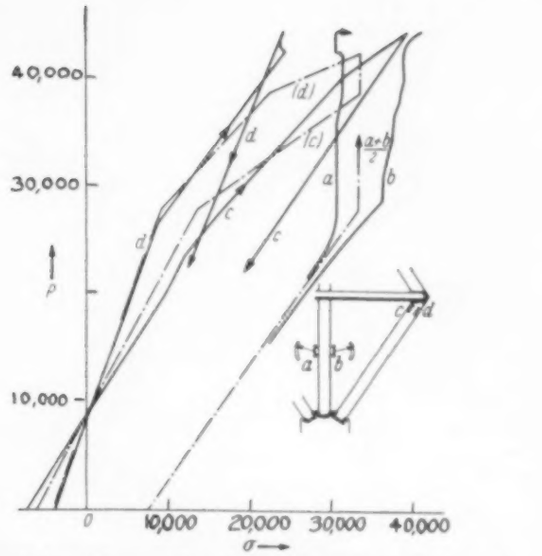

Fig. 3—Load-Stress Diagrams Recorded by Huggenberger Extensometers at Four Gage Lengths on the Vertical and Diagonal Bars

— · — · — calculated
——— observed

Beyond the yield stress of the vertical tension bar, the diagonal bars assume larger proportions of the external load. The initial shrinkage stresses account for the displacement of curves a and b with respect to curves c and d

P = external load, lb.

σ = stress lb./in.^{2} deduced from strains recorded by the extensometers. The flow figures in the vertical tension bar at and beyond the yield stress did not occur within the gage length of the extensometer

did not take part in the yielding as shown in Fig. 3. The flow figures occurred at the center rather than at the edges of the bar because rolling stresses were present. Although flow figures did not tend to occur at the welds, it should be pointed out that if the framework is to be designed for service in which fatigue stress predominates, design based on plastic behavior is not justified.

The behavior of the vertical tension bar having been shown to depend on extremely localized yield, the behavior of the horizontal compression bar was investigated in frameworks of the same type but in which the tension members were made excessively heavy. When the buckling load of the compression bar (in reality, two flat bars) was attained, the load rapidly dropped, Fig. 4. The bar buckled in the direction of distortion due to welding. The slightly higher yield strength exhibited by the strained specimen 8 days after initial testing was ascribed to aging.

If the compression bar was fillet welded to the vertical tension bar at the center, the maximum load attained, Fig. 5, was a little higher than without welding. Otherwise, behavior in both specimens was identical. Yield occurred first in the vertical tension bar. Shortly thereafter, the compression bar buckled and carried the tension bar with it. The buckles were single-bay type. The resistance of the remainder of the framework to twisting raised the buckling limit of the compression bar. In both specimens compressive shrinkage stress in the compression bar due to welding lowered the expected maximum load. Consequently, if the strength of a statically indeterminate structure depends on the buckling strength of a member, the shrinkage stresses created by welding should be known.

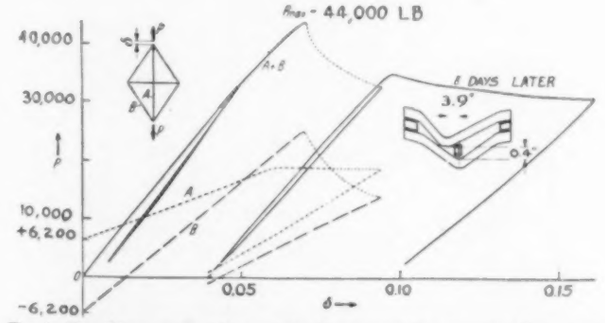

Fig. 4—The Effect of Buckling of the Horizontal Compression Bar on the Welded Statically Indeterminate Framework. The Compression Bar Had a Slight Initial Curvature Due to Welding Distortion. The Vertical Tension Bar Was Not Welded to the Compresson Bar. Sketch Shows Buckled Compression Bar After Test

As in Figs. 1 and 2, lines A and B are the load-extension diagrams for the two determinate parts of the framework. The initial shrinkage load caused by welding was 6230 lb. tension in the vertical tension bar and 6230 lb. compression in the diagonal bars.

P = load, lb.; δ = elongation of entire framework or determinate component in the direction of load, inches

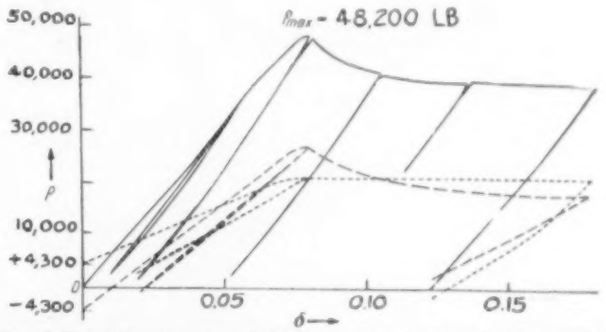

Fig. 5—Same Framework as Fig. 3 but Compression Bar Was Fillet Welded to the Tension Bar. The Initial Shrinkage Load Due to Welding Was 4300 Lb. Tension in the Vertical Tension Bar and 4300 Lb. Compression in the Diagonal Bars

P = load, lb.

δ = elongation of entire framework or separate components in the direction of load inches

UNFIRED PRESSURE VESSEL REPAIRS

By C. C. ASHLEY*

NOTE: *Submitted in reply to a questionnaire on* Distortions and/or Failures Due to Welding *circulated among welding experts by the Fundamental Research Division, Welding Research Committee.*

WHEN a crack appears in a pressure vessel, the patching procedure depends on the depth of the crack. Where the cracks do not extend through the wall, U-shaped grooves are cut with well rounded ends, being careful that the groove extends further than the crack both in depth and length. Where the cracks extend through, U-shaped grooves from both sides are cut with the edges of the two plates about $^1/_4$ inch apart at the bottom of the grooves. Where cracks have appeared in the original welded joints of the vessels, the old weld-metal is chipped out clean and the joint double butt welded again, the cross section of the joint substantially corresponding to the original. In some instances a considerable portion of the wall must be renewed, and flanged patches are used. The flanged part of the patch is about half the wall thickness and rests on the inner surface of the vessel. The section of the groove between wall and patch is substantially U-shaped. The section of the weld at the edges of the flange simulates a quadrant of a circle. This procedure is illustrated in Figs. 1, 2 and 3.

Fig. 1

In repairs which are relatively long as compared to the width, cracking may occur at the end of the weld while welding. In such cases it is possible that the minute hair line of the original crack has not been completely over-reached in chipping the welding groove; thus, providing excessive stress concentration at the end due to the expansive force of the welding material while heating and peening.

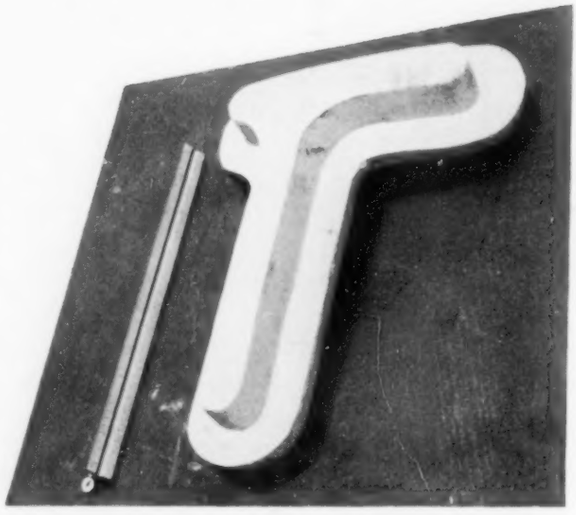

Fig. 2

Arc welding is employed with due attention to generator voltage and current, and to quality of electrode. Preheating is not adopted because the entire vessel never can be preheated uniformly. Stress relieving is not employed, and if the cooling rate is practically uniform, there is no object in particularly slow cooling. However, it is most essential that the sequence of welding be correct. The beads are deposited in alternate layers on both sides of the groove. Success is not attainable unless peening is resorted to. Failure in the welding attempt is disclosed by cracking during cooling after withdrawing the electrode.

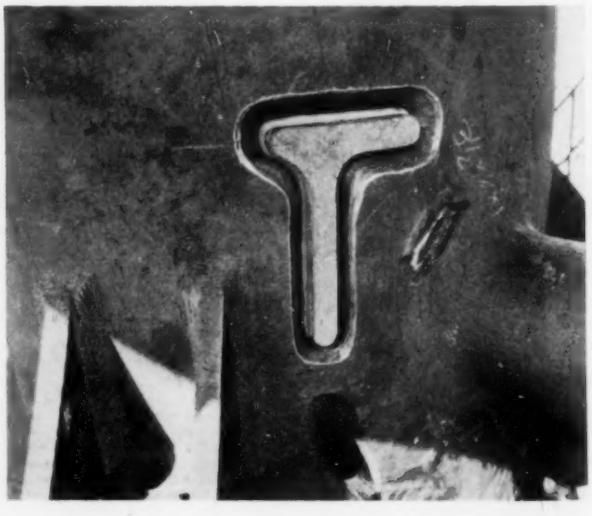

Fig. 3

*Shell Oil Company.